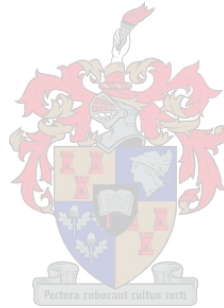


**IDENTIFYING AFRICAN WILD DOG (*LYCAON PICTUS*) CORRIDORS
OUTSIDE GONAREZHOU NATIONAL PARK AND SAVÈ VALLEY
CONSERVANCY USING MAXENT SPECIES DISTRIBUTION MODELING**

KUDZANAI ROSEBUD MAREMBO(BSc Honours Geoinformatics)

*Thesis submitted in fulfilment of the requirements for the degree Master of Science (in
Geoinformatics) in the Faculty of Science at Stellenbosch University.*



SUPERVISOR: DR H M DE KLERK

CO-SUPERVISOR: DR R J GROOM

March 2015

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature:

.....

Date:

.....

ABSTRACT

The African wild dog (*Lycaon pictus*) is one of the most endangered large carnivores. Gonarezhou National Park (GNP) and Savè Valley Conservancy (SVC) that hold part of the few remaining viable populations report that wild dog populations continue to decline due to high rates of habitat loss and fragmentation. This leads to low pup survival rates due to predators and reduced formation of new packs as the wild dogs have become reluctant to leave the safety of their original packs in pursuit of mating partners in fragmented habitats where higher risks of danger exist. Consequently, this reduces population growth for *Lycaon pictus*. Therefore, the study sought to identify additional suitable habitat for wild dog outside GNP and SVC and a corridor connecting the two areas using the ecological niche theory.

Wild dog satellite collar data from the African Wildlife Conservation Fund (AWCF) was used with spatial and climate data for GNP and SVC from PeaceParks and WorldClim. This data was used to firstly, identify dens using ArcGIS 10.1. Secondly, map geographic and temporal distributions using Time Local Convex Hull (T-LoCoH). Thirdly, to assess biotic and abiotic drivers of different packs and sexes movement and distribution patterns using ARCGIS 10.1 and lastly, map probability distributions (corridor and re-location sites) using Maximum Entropy (MaxEnt).

Den locations are in areas away from predators and human settlements. Wild dog geographic distributions are smaller in the cold and dry seasons and differ according to sex whilst temporal distributions depend on their use of resources. The most influential biotic and abiotic variables within reserves were distance to human settlements and elevation whilst the least influential were roads and temperature. However, outside the reserves, the most influential variable was distance from reserve. Malilangwe is a potential corridor between GNP and SVC, whilst Masvingo, Beitbridge, and Mwenezi districts have suitable habitat for re-location sites.

KEY WORDS AND PHRASES

Wild dog (*Lycaon pictus*), Utilization Distribution (UD), Species Distribution Modelling (SDM), Wildlife corridors

OPSOMMING

Die Afrika-wildehond (*Lycaon pictus*) is een van die mees bedreigde groot karnivore. Gonarezhou Nasionale Park (GNP) en Savè Vallei Conservancy (SVC) wat deel van die min oorblywende lewensvatbare bevolkings hou rapporteer dat wilde hond bevolkings voortgaan om te daal as gevolg van die verlies en fragmentering van habitat. Dit lei tot 'n lae pup oorlewingsyfer te danke aan predasie asook dalende vlakke van nuwe troppe. Omdat as die wilde honde het huiwerig geword om die veiligheid van hul oorspronklike troppe te verlaat in die soektog na paarmaats in gefragmenteerde habitate waar hoër risiko van gevaar bestaan. Gevolglik verminder die bevolkingsgroei vir *Lycaon pictus*. Daarom onderneem die studie addisionele geskikte habitat vir wilde hond buite die GNP en SVC te vind en die stigting van 'n gang Om die twee gebiede te verbind met behulp van die ekologiese nis teorie te identifiseer.

Wildehond satelliet kraag data van die African Wildlife Conservation Fund (AWCF) is gebruik met ruimtelike en klimaat data vir die GNP en SVC van PeaceParks en WorldClim. Hierdie data is gebruik om eerstens, kuile te identifiseer met behulp van ArcGIS 10.1. Tweedens, kartering van geografiese en temporale verspreiding met behulp van Time Local Convex Hull (T-LoCoH). Derdens, die ondersoek van biotiese en abioties dryfkragte van verskillende troppe pakke en geslagte bewegings en verspreidingspatrone met ArcGIS 10.1 te evalueer en laastens, kartering van waarskynlikheidsverdelings (korridor en hervestigingsgebiede) van die Maksimum Entropie (MaxEnt).

Kuile is in gebiede weg van roofdiere en menslike nedersettings. Wildehond geografiese verspreiding is kleiner in die koue en droë seisoene en verskil volgens geslag, terwyl temporale verspreidings afhang van die gebruik van hulpbronne. Die mees invloedryke biotiese en abioties veranderlikes binne reserwes was die afstand vanaf menslike nedersettings en hoogte, terwyl paaie en temperatuur die laagste invloed gehad. Buite die reserwes was, die mees invloedryke veranderlike afstand vanaf reservaat. Malilangwe is 'n potensiële korridor tussen die GNP en SVC, terwyl Masvingo, Beitbridge en Mwenezi distrikte geskikte habitat bied vir hervestiging.

TREFWOORDE

Wildehond (*Lycaon pictus*), Utilization Distribution (UD), Species Distribution Modelling (SDM), Wildlife gange

ACKNOWLEDGEMENTS

Thanks are owing to:

- The academic staff of the Department of Geography and Environmental Studies, Stellenbosch University, for academic and technical support.
- Dr. Helen de Klerk, my supervisor for numerous discussion sessions, encouragement and all round support.
- Dr. Rosemary Groom, my co-supervisor for providing me with wild dog data and being key in my understanding of wild dog ecology.
- Collared wild dog in Gonarezhou National Park and Savè Valley Conservancy from 2009 to 2013 that made the study possible.
- Dr. Luck-Vogel, Mokhine, Michelle, Nyasha, Richardt, Stephe and Thendo, my research group whom I bounced ideas off of and sought advice.
- Mrs. Joan Marembo, my mother for her inspiration and encouragement. I proudly dedicate this thesis to her; I would not have succeeded without her support.
- Mr. Jay Gwena, my husband for being my number one fan and constantly reminding me I could do it.
- Mr. Kingston M Marembo and Mrs. Diana Madabu, my late father and grandmother whom I miss every day, life is not the same without you.
- Onevea Marembo, Freeman Marembo, Valerie Marembo, Rumbidzai Gwanzura and Joan Madabu, my siblings whom are my everything.
- My good friends Melissa Matavire, Tapiwa Chatikobo and Caroline Gurajena for their encouragement.
- God, my Lord and saviour whose mercy and grace is sufficient for me every day, in Him I am renewed.

CONTENTS

DECLARATION	ii
ABSTRACT	iii
OPSOMMING	iv
ACKNOWLEDGEMENTS	v
CONTENTS	vi
TABLES	i
FIGURES	i
APPENDICES	v
ACRONYMS AND ABBREVIATIONS	vi
CHAPTER 1: OVERVIEW OF WILD DOG CONSERVATION	1
1.1 CONTEXTUALISING CONSERVATION FOR THE AFRICAN WILD DOG	1
1.2 PROBLEM FORMULATION	2
1.3 SIGNIFICANCE	3
1.4 AIM AND OBJECTIVES	4
1.5 STUDYING AND MAPPING WILD DOG ECOLOGY	4
1.6 RESEARCH DESIGN	5
1.7 THESIS STRUCTURE	7
CHAPTER 2: CAUSES AND POSSIBLE SOLUTIONS FOR AFRICAN WILD DOG CONSERVATION	8
2.1 THE AFRICAN WILD DOG (<i>LYCAON PICTUS</i>)	9
2.2 CONSERVATION STATUS	9
2.2.1 Main causes of declining populations	10
2.2.2 Proposed methods to counter population decline	11

2.3	WILDLIFE ECOLOGICAL CORRIDORS	12
2.4	WILD DOG MOVEMENT AND CONNECTIVITY.....	13
2.4.1	Collecting wild dog locality data.....	14
2.4.2	Wild dog denning	15
2.5	WILD DOG UTILIZATION DISTRIBUTION.....	16
2.6	MODELLING WILD DOG POTENTIAL DISTRIBUTION.....	18
2.6.1	Presence-only, presence-absence and pseudo-absence data.....	19
2.6.2	Scale and sample size	19
2.6.3	Variable selection	20
2.6.3.1	Biotic variables.....	21
2.6.3.2	Abiotic variables	22
2.6.4	Model selection	23
2.6.5	Model evaluation	24
2.7	CONCLUSION.....	25
CHAPTER 3: ECOLOGICAL MODELLING TO SUGGEST WILD DOG		
	CORRIDORS	27
3.1	STUDY AREA.....	28
3.2	DATA	30
3.2.1	Wild dog ethical considerations	30
3.2.2	Data Collection	31
3.2.3	Sampling and scale	33
3.3	METHODS	34
3.4	DENNING.....	35
3.5	WILD DOG UTILIZATION DISTRIBUTION.....	35
3.5.1	Geographic distribution.....	36
3.5.2	Temporal distributions	36
3.6	WILD DOG PROBABILITY DISTRIBUTION.....	36

3.6.1	Variables influencing movement and distribution	37
3.6.1.1	Biotic variables.....	39
3.6.1.2	Abiotic variables	41
3.6.1.3	Investigation of relationship between variables	43
3.6.2	Accessible areas to wild dog: model selection	44
3.7	EXPERIMENTAL DESIGN	46
CHAPTER 4: WILD DOG DENNING		47
4.1	DENNING SITES	47
4.2	DENNING DURATION	49
4.3	DENNING INFLUENCE ON MOVEMENT PATTERNS	50
CHAPTER 5: WILD DOG ACTUAL USE OF SPACE		52
5.1	CHARACTERISTICS OF WILD DOG USE OF SPACE	52
5.2	UTILIZATION DISTRIBUTIONS EXTENT	55
5.3	GEOGRAPHIC AND TEMPORAL DISTRIBUTIONS	58
5.3.1	UDs and re-visitation rates and duration of stay in GNP.....	59
5.3.2	UDs and re-visitation rates and duration of stay in SVC	62
5.3.3	Relationship between geographic and temporal distributions.....	68
CHAPTER 6: WILD DOG PROBABILITY DISTRIBUTION		71
6.1	ACCESSIBLE AREAS TO WILD DOG	71
6.2	VARIABLES INFLUENCING MOVEMENT AND DISTRIBUTION	72
6.2.1	Biotic variables	73
6.2.1.1	Human settlements	73
6.2.1.2	Roads.....	76
6.2.1.3	Reserve boundary	79
6.2.2	Abiotic variables	81
6.2.2.1	Elevation.....	81

6.2.2.2	Rivers	84
6.2.2.3	Vegetation	87
6.2.2.4	Rainfall	90
6.2.2.5	Temperature	93
6.2.3	Relationship between variables.....	96
6.2.4	Variables contribution to models' output	99
6.2.4.1	Variable effect on prediction.....	99
6.2.4.2	Variable permutation importance within the reserves.....	102
6.3	MODEL ACCURACY	105
6.4	CONCEPTUAL CORRIDORS	108
CHAPTER 7: ARE SDM SUITABLE FOR IDENTIFYING CONCEPTUAL WILD DOG CORRIDORS?.....		113
7.1	CONCLUSIONS	113
7.2	RE-VISITING OBJECTIVES	114
7.3	STUDY EVALUATION	115
7.4	RECOMMENDATIONS.....	116
REFERENCES		118
PERSONAL COMMUNICATIONS		136
APPENDICES		137

TABLES

Table 3.1 Wild dog packs' collar ID, pack name, sex and the years collared in GNP that were used in the study	31
Table 3.2 Wild dog packs' and individual dog collar ID, pack name, sex and the years collared in SVC that were used in the study	31
Table 3.3 Landsat scenes ID, path and row, date acquired by sensor used for display in the study	32
Table 3.4 Comparison of resolution and description of different DEM available for Zimbabwe	33
Table 3.5 Biotic and abiotic variables derived from the seasonal distributions used in wild dog distribution model to determine other areas that wild dog can survive outside GNP and SVC	38
Table 4.1 Denning start and end dates per year for five wild dog collared packs in SVC from 2011 to 2012	49
Table 5.1 Total area in km ² for the UDs for each of the collared packs in GNP and SVC in both the cold and dry, and hot and wet season	56
Table 6.1 Comparison of male and female wild dog proportions in different rainfall ranges for the cold and dry and hot and wet season in GNP and SVC	92
Table 6.2 Comparison of male and female wild dog proportions in different temperature ranges for the cold and dry and hot and wet season in GNP and SVC.....	95
Table 6.3 Correlation between biotic variables in the cold and dry season in both GNP (A) and SVC (B).....	96
Table 6.4 Correlation between abiotic variables in the cold and dry season in both GNP (A) and SVC (B).....	97
Table 6.5 Correlation between abiotic variables in the hot and wet season in both GNP (A) and SVC (B).....	97
Table 6.6 Variables autocorrelations calculation in SPSS for GNP using two tailed Pearson's correlation.....	97
Table 6.7 Variables autocorrelations calculation in SPSS for SVC using two tailed Pearson's correlation.....	98

Table 6.8 MaxEnt model analysis of each variables contribution to wild dog prediction models in GNP and SVC	103
Table 6.9 BIOMOD variables importance in the GLM, GAM, and MaxEnt models for GNP and SVC	103

FIGURES

Figure 1.1 Steps followed in chronological order to apply species distribution modelling in identifying ecological corridors for the African wild dog in south-eastern Zimbabwe.	6
Figure 3.1 Ecological niche modelling concept showing the interaction between biotic and abiotic space for a species	27
Figure 3.2 Gonarezhou National Park and Savè Valley Conservancy, two reserves in south-eastern Zimbabwe that formed the study areas	29
Figure 3.3 Human settlements in GNP (A) and SVC (B) with buffers of 5 to 20 km.	39
Figure 3.4 Roads in GNP (A) and SVC (B) with buffers of 5 to 20 km.....	40
Figure 3.5 Buffers of 5 to 20 km from the boundaries of GNP (A) and SVC (B).....	41
Figure 3.6 Rivers in GNP (A) and SVC (B) with buffers of 1.25 to 5 km	42
Figure 3.7 Effect of the value of MaxEnt's' regularization multiplier with values 1 (A), 4 (B) and 7 (C) on the response curves showing the influence of distance to human settlements in GNP on the MaxEnt prediction. It plots logistic prediction on the y-axis against its weight in the model on the x-axis	45
Figure 3.8 Experimental design giving systematic detail of the methods used in the study in their chronological order.....	46
Figure 4.1 Den locations for five of the collared packs in SVC from 2011 to 2012. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25.....	48
Figure 4.2 Denning timeline for five wild dog collared packs in SVC from 2011 to 2012.....	50
Figure 4.3 Wild dog locality points during the denning season in SVC expressed as percentages to represent the distance from the den sites wild dog maintained.....	51
Figure 5.1 Distribution of the four collared wild dog packs in GNP used in the study from 2010 to 2013 (A to D). Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25	53
Figure 5.2 Distribution of the nine collared packs and two individual wild dog in SVC used in the study from 2009 to 2013 (A to E). Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25.....	54

Figure 5.3 Comparison of female and males UD extents in the cold and dry (A), and hot and wet (B) season in both GNP and SVC	57
Figure 5.4 Comparison of UD extents of different packs in SVC for the cold and dry (A), and hot and wet (B) seasons	57
Figure 5.5 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Mabalauta (Female) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25	60
Figure 5.6 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Shangana (Male) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25	61
Figure 5.7 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Patch (Female) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25	63
Figure 5.8 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Tick (Male) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25	65
Figure 5.9 Isopleths for Batanai, Crocodile, Mambira, and Mapura in the cold and dry season (A, E, I and K) and the hot and wet season (B, F, J and L) as well as re-visitation rates and durations of stay for the cold and dry season (C, G, M and O) and the hot and wet season (D, H, N and P) in SVC. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25.....	67
Figure 5.10 Relationship between a species re-visitation rate, duration of stay and the resources it uses in its UD where A is the explanation given by T-LoCoH and B is the interpretation used by the study.....	69
Figure 6.1 BIOMOD Kappa and ROC AUC results for GAM, GLM and MaxEnt SDM over 15 replicates within and outside the reserves for (a) GNP and (b) SVC. Note higher Kappa and ROC AUC values represent better model accuracy	72

Figure 6.2 GNP and SVC proportions of wild dog locality points in 5 to 20 km buffer distances from human settlements for the cold and dry and hot and wet seasons	74
Figure 6.3 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from human settlements for the cold and dry and hot and wet seasons in both GNP and SVC	75
Figure 6.4 GNP and SVC proportions of wild dog locality points in 5 to 20 km buffer distances from roads for the cold and dry and hot and wet seasons	77
Figure 6.5 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from roads for the cold and dry and hot and wet seasons in both GNP and SVC.....	78
Figure 6.6 Proportions of wild dog locality points in 5 to 20 km buffer distances from GNP and SVC's boundary during the cold and dry and hot and wet seasons	80
Figure 6.7 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from GNP and SVC's boundaries for the cold and dry and hot and wet seasons	80
Figure 6.8 GNP and SVC proportions of wild dog locality points at different elevation ranges for the cold and dry and hot and wet seasons.....	82
Figure 6.9 Comparison of male and female wild dog proportions in different elevation ranges for the cold and dry and hot and wet seasons in GNP and SVC	83
Figure 6.10 GNP and SVC proportions of wild dog locality points in 5 to 20 km buffer distances from rivers for the cold and dry and hot and wet seasons	85
Figure 6.11 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from rivers for the cold and dry and hot and wet seasons in GNP and SVC	86
Figure 6.12 GNP and SVC proportions of wild dog locality points in different vegetation types for the cold and dry and hot and wet seasons	88
Figure 6.13 Comparison of male and female wild dog proportions in different vegetation types for the cold and dry and hot and wet seasons in both GNP and SVC	89
Figure 6.14 GNP proportions of wild dog locality points at different rainfall ranges for the cold and dry (blue) and hot and wet (red) seasons	90
Figure 6.15 SVC proportions of wild dog locality points at different rainfall ranges for the cold and dry (blue) and hot and wet (red) seasons	91

Figure 6.16 GNP proportions of wild dog locality points at different temperature ranges for the cold and dry (blue) and hot and wet (red) season.....	93
Figure 6.17 SVC proportions of wild dog locality points at different temperature ranges for the cold and dry (blue) and hot and wet (red) seasons	94
Figure 6.18 Response curves for the variables effect on predictions in GNP plotted as logistic prediction on the y-axis against its weight in the model on the x-axis for two biotic variables (a) Distance to human influences, and (b) Distance to reserve boundary, and three environmental variables (c) elevation, (d) Distance to rivers, and (e) vegetation	100
Figure 6.19 Response curves for the variables effect on predictions in SVC plotted as logistic prediction on the y-axis against its weight in the model on the x-axis for two biotic variables (a) Distance to human influences, and (b) Distance to reserve boundary, and three environmental variables (c) elevation, (d) Distance to rivers, and (e) vegetation	101
Figure 6.20 Jackknife tests for the variables effect on predictions in GNP (A) and SVC (B)....	102
Figure 6.21 GNP and SVC wild dog probability distribution mapped with MaxEnt using red to blue to show highest to lowest probability of occurrence	105
Figure 6.22 MaxEnt model's omission/commission graphs for GNP (A) with a fractional value of 0.6, and SVC (B).....	107
Figure 6.23 Variable permutation importance in MaxEnt distribution model for areas outside GNP and SVC in south-eastern Zimbabwe	108
Figure 6.24 Variable permutation importance in BIOMOD's GAM, GLM, and MaxEnt distribution models for areas outside GNP and SVC in south-eastern Zimbabwe .	109
Figure 6.25 South-eastern Zimbabwe wild dog probability distribution outside the border of GNP and SVC mapped with MaxEnt using red to blue to show highest to lowest probability of occurrence.....	110
Figure 6.26 Malilangwe conceptual corridor connecting GNP and SVC	111

APPENDICES

APPENDIX A: T-LOCOH SCRIPT IN R FOR WILD DOG PACKS	157
APPENDIX B: BIOMOD SCRIPT IN R FOR THE WILD DOG PACKS	159
APPENDIX C: ADDITIONAL T-LOCOH GEOGRAPHICAL AND TEMPORAL DISTRIBUTIONS WILD DOG PACKS	162
APPENDIX D: WILD DOG RE-VISITATION RATES AND DURATION OF STAY PLOTTED USING ISOPLETHS COLOUR CODE AND CORRESPONDING MAPS IN DIFFERENT SEASONS	166
APPENDIX E: MAXENT RESPONSE CURVES RESULTS PER PACK	181
APPENDIX F: MAXENT VARIABLES JACKKNIFE TESTS RESULTS PER PACK ..	186
APPENDIX G: MAXENT VARIABLE PERMUTATION IMPORTANCE PER PACK	189
APPENDIX H: MAXENT OMISSION/COMMISSION GRAPHS RESULTS PER PACK	190
APPENDIX I: MAXENT WILD DOG DISTRIBUTION MODELS PER PACK	193
APPENDIX J: MAXENT WILD DOG DISTRIBUTION OUTSIDE GNP AND SVC OUTPUTS	198
APPENDIX K: ETHICAL CLEARANCE	200

ACRONYMS AND ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection
AWCF	African Wildlife Conservation Fund
DEM	Digital Elevation Model
GAM	Generalized Additive Model
GIS	Geographic Information Systems
GLM	Generalized Linear Model
GLTFCA	Greater Limpopo Transfrontier Conservation Area
GME	Geospatial Modelling Environment
GNP	Gonarezhou National Park
GPS	Global Positioning Systems
IUCN	International Union for Conservation of Nature
IVG	Inter-Visit Gap
KDE	Kernel Density Estimation
MaxEnt	Maximum Entropy
MP	Maximum Polygon
MCP	Minimum Convex Polygon
MNLV	Mean Number of Locations per Visit
MTD	Maximum Theoretical Distance
NSV	Number of Separate Visits
ROC AUC	Receiver Operating Characteristic Area Under the Curve
RSF	Resource Selection Functions
<i>S</i>	Scaling Parameter
SDM	Species Distribution Modelling
SRTM	Shuttle Radar Topography Mission
SVC	Savè Valley Conservancy
T-LoCoH	Time Local Convex Hull
TSD	Time-Scale Distance
UD	Utilization Distribution

CHAPTER 1: OVERVIEW OF WILD DOG CONSERVATION

The African wild dog (*Lycaon pictus*) (hereafter, wild dog) is an efficient and successful hunter (Courchamp & Macdonald 2001) with the largest canid litter size (McNutt & Silk 2008). Despite their superior hunting skills, wild dogs are categorised as the most endangered large carnivore on the International Union for Conservation of Nature (IUCN) Red List due to population declines in much of its sub-Saharan African range (Woodroffe & Sillero-Zubiri 2012). Therefore, there is a need to direct effort into conservation measures for wild dog current distribution in southern Africa. This is because in southern Africa, their populations may have chances of increasing, which will in turn minimise the risk of their global extinction (Lindsey, du Toit & Mills 2004; Hayward et al. 2007).

1.1 CONTEXTUALISING CONSERVATION FOR THE AFRICAN WILD DOG

Movements of large carnivores such as wild dog (Rasmussen & Macdonald 2011) are not random as their utilization distributions (UDs) have a positive correlation with the available resources in their geographical space (Caro, Jones & Davenport 2009; Epps et al. 2011). Mapping UD helps to make an approximation of an animal's home-range. Wild dog have been identified as a keystone species due to their complex ecology that can represent resources available for other species in an area and their reducing populations are an indicator of the decrease of biodiversity (Lindsey, du Toit & Mills 2004; Epps et al. 2011). Wild dog are a social species that live in packs of various sizes (Creel & Creel 2002; Marsden et al. 2011) where they communally participate in ecological activities including hunting and denning (Woodroffe et al. 2007; Davies-Mostert et al. 2012), which require large geographic spaces (Becker et al. 2012). Whilst reserves meet space provision requirements for wild dog, habitat fragmentation and loss in these areas is a major challenge because it restricts wild dog movement (Büscher & Schoon 2009; Woodroffe & Sillero-Zubiri 2012). Restricted movement negatively affects wild dog reproduction, as they have to emigrate and form new packs in order to increase population (Kratt & Kratt 2013). The ability to move beyond reserve borders would be favourable for wild dog in search of mating partners and space to form new packs (Buettner et al. 2007) as well as more secure places to den (Woodroffe & Sillero-Zubiri 2012). However, due to persecution beyond reserve borders, movement there is limited (Gusset et al. 2009). This has highlighted the need for studies to identify additional wild dog habitat known as "areas of connectivity" for wild dog are areas where they can be re-located (hereafter, wild dog

corridors) beyond reserve borders (Groom 2013a, Pers com). Ideally, these corridors would allow free movement between reserves and provide space for new pack formations, consequently increasing wild dog reproduction and in turn, population size (Frantzen, Ferguson & de Villiers 2001).

Corridors are defined as areas that enhance habitat connectivity by facilitating the exchange of individuals between populations (Almany et al. 2009), or areas with the capacity to sustain ecological changes and interactions (Saura et al. 2011). These corridors facilitate maintaining ecological connections, protecting complex ecosystem functions and providing a link between different reserves (Büscher & Schoon 2009; Goldman 2009; Graham et al. 2009; Klein et al. 2009; Thaker et al. 2011; Pittiglio et al. 2012). This makes wildlife corridors important in conservation planning, because they are an acceptable indicator of biodiversity richness of an area (Chape et al. 2006). Scientists assume an area that manages to sustain ecological changes and interactions of different species has evidence of intact habitat connectivity (Darnell et al. 2014). This leads to promotion of survival and growth of vulnerable and endangered species (Buettner et al. 2007; Bennet & Saunders 2010; Rondini & Chiozza 2010). To assess habitat connectivity for a species, the movement and distribution patterns should be studied (Conlisk et al. 2013). Both biotic and abiotic variables influence species movements and distributions (Soberón & Peterson 2005). Species locality data delineates the geographical space whilst the biotic and abiotic variables explain why the species uses that space. An increasing number of methods are available to map and explain different characteristics of species location, movement, and distribution patterns. To identify the geographical space and UD software is available and to explain the geographical space, methods known as species distribution models (SDMs) have been developed (Svenning et al. 2011). SDMs model factors that influence distributions in order to understand the impact of these factors on distribution and predict where a species can or cannot persist.

1.2 PROBLEM FORMULATION

Continuing decline of wild dog populations has raised concern that the species may be on the brink of extinction (Rasmussen & Macdonald 2011; Groom 2013b, Pers com). Causes for the population declines are mostly due to habitat loss and fragmentation (Hayward et al. 2006; Lindsey et al. 2011; Cloutier & Packard 2014) and predation by lions (*Panthera leo*) and other large carnivores (McNutt & Silk 2008; Vanak et al. 2013; Swanson et al. 2014). In addition, high mortality rates during

hunting (Kratt & Kratt 2013), human-wildlife conflict (Patterson et al. 2004; Davies-Mostert et al. 2012), snaring (Leigh 2005), infectious disease (Woodroffe & Donnelly 2011) and an imbalance between the species populations and available resources (Becker et al. 2012) also contribute to wild dog population declines. Whilst wild dog ecology has been widely studied in south-western (Lindsey et al. 2011), and south-eastern (Marsden et al. 2011; Mbizah & Groom 2011) Zimbabwe, understanding major drivers of wild dog movements and distribution in these areas is still required. One way of studying these drivers is through assessing whether the habitat connecting two reserves will be suitable for wild dog (Saura et al. 2011). This is important for wild dog, but also because habitat connectivity for keystone species maintains or enhances biodiversity conservation, improves species interaction, avoids anthropogenic influences and reduces habitat fragmentation and degradation (Pressey et al. 2007; Rasmussen & Macdonald 2011). A potential solution to counter wild dog population loss and understand the major drivers of their movement and distribution patterns is identifying wild dog corridors with suitable habitat connectivity between different conservation areas such as national parks, conservancies, and game reserves (Beier, Majka & Newell 2009; Goldman 2009). Therefore, there is need to propose corridors with suitable habitat connectivity in south-eastern Zimbabwe (Lindsey, du Toit & Mills 2004; Groom 2013a, Pers com) using methods that will be suitable for the species' long-term conservation.

1.3 SIGNIFICANCE

In general, wild life corridors for large carnivores that are keystone species will also include other species. For example, wild dog corridors include vultures that feed on wild dog leftovers after kills (Frantzen, Ferguson & de Villiers 2001; Becker et al. 2012). In addition, whilst dens (Romañach & Lindsey 2007) and prey (Courchamp, Rasmussen & Macdonald 2002) are well-studied drivers of wild dog movement and distribution patterns, this study will add other biotic and abiotic variables to this list. Finally, the study's most important contribution is the identification of ecological corridors and areas with intact habitat for wild dog that can eventually serve as re-location sites. This will potentially increase wild dog populations by identifying new locations appropriate for pack formation, mating, and denning (Kratt & Kratt 2013).

1.4 AIM AND OBJECTIVES

Gonarezhou National Park (GNP) and Savè Valley Conservancy (SVC) are two reserves in south-eastern Zimbabwe, which are home to part of the remaining largest wild dog populations (Groom 2013b, Pers com; Mbizah et al. 2014). However, both GNP and SVC are currently experiencing large amounts of habitat fragmentation (Gandiwa et al. 2011) which has led to the loss of wild dog habitat and their populations declining. One way to counter this challenge is to identify additional habitat for wild dog outside GNP and SVC based on their current distribution. Therefore, the study aims to identify wild dog corridors outside GNP and SVC, as well as re-location sites, to enhance wild dog population growth by modelling wild dog distribution using UD mapping and SDM techniques.

The following objectives satisfied the aim:

- To assess the literature on wild dog, wildlife corridors, utilization distribution mapping, and species distribution modelling,
- To identify wild dog denning locations and periods of denning seasons
- To map wild dog utilization distributions in GNP and SVC
- To identify biotic and abiotic factors influencing wild dog movement and distribution patterns
- To model wild dog movement and distributions in GNP and SVC using SDM

1.5 STUDYING AND MAPPING WILD DOG ECOLOGY

This section briefly summarizes the focus of the literature review and the methods used to identify the wild dog denning locations and durations, UD, variables influencing movement and distribution, and to model probability distribution.

The literature review highlighted that studying wild dogs is beneficial not only in influencing measures to increase their population but also because as a keystone species, their conservation measures also contribute to conservation needs of other species (Caro, Jones & Davenport 2009).

One characteristic of the wild dogs' ecology is the denning season during which they tend to pups. If majority of the pups survive past this denning stage, it is a successful denning season (Lindsey et al. 2011). Wild dogs' movement and distribution patterns alter between seasons illustrating how different ecological processes influence the wild dogs UD size (Jachowski et al. 2010). Biotic and abiotic drivers of wild dog ecology also shape their movement and distribution patterns (Becker et al. 2012). Species movement and distribution patterns can be explained by SDM and used to map probability distributions (Phillips & Elith 2013).

The study used coordinates from wild dogs' satellite collars as the main data input for the study together with buffer and cluster analysis in ArcGIS 10.1 to identify dens. Time and date stamps from the collar data determined denning durations.

UDs are used to define the geographical locations and space-use of animals in a given study area (Pebsworth, Morgan & Huffman 2011). T-LoCoH calculated the UD using 95% isopleth levels, to define the return rate of the dog to different locations and their duration of stay (Lyons, Turner & Getz 2013).

Literature and expert knowledge identified biotic (human settlements, roads, reserve boundary) and abiotic (elevation, rivers, vegetation, rainfall, temperature) variables influencing seasonal wild dog movement and distribution (Caley, Tennant & Hood 2011). The study assessed their influence using buffers and tabulated intersections in ArcGIS 10.1. Maximum Entropy (MaxEnt) SDM mapped wild dog probability distribution patterns outside GNP and SVC. Model accuracy was tested using the area under the receiver operating characteristic area under the curve (ROC AUC) (Edren et al. 2010; Jiménez-Valverde 2012).

1.6 RESEARCH DESIGN

Figure 1.1 presents all the steps followed in the study in chronological order to apply species distribution modelling in identifying ecological corridors for the African wild dog in south-eastern Zimbabwe. These steps include the problem formulation, a literature re-view, data collection, each of the methods described above and the results drawn from the study.

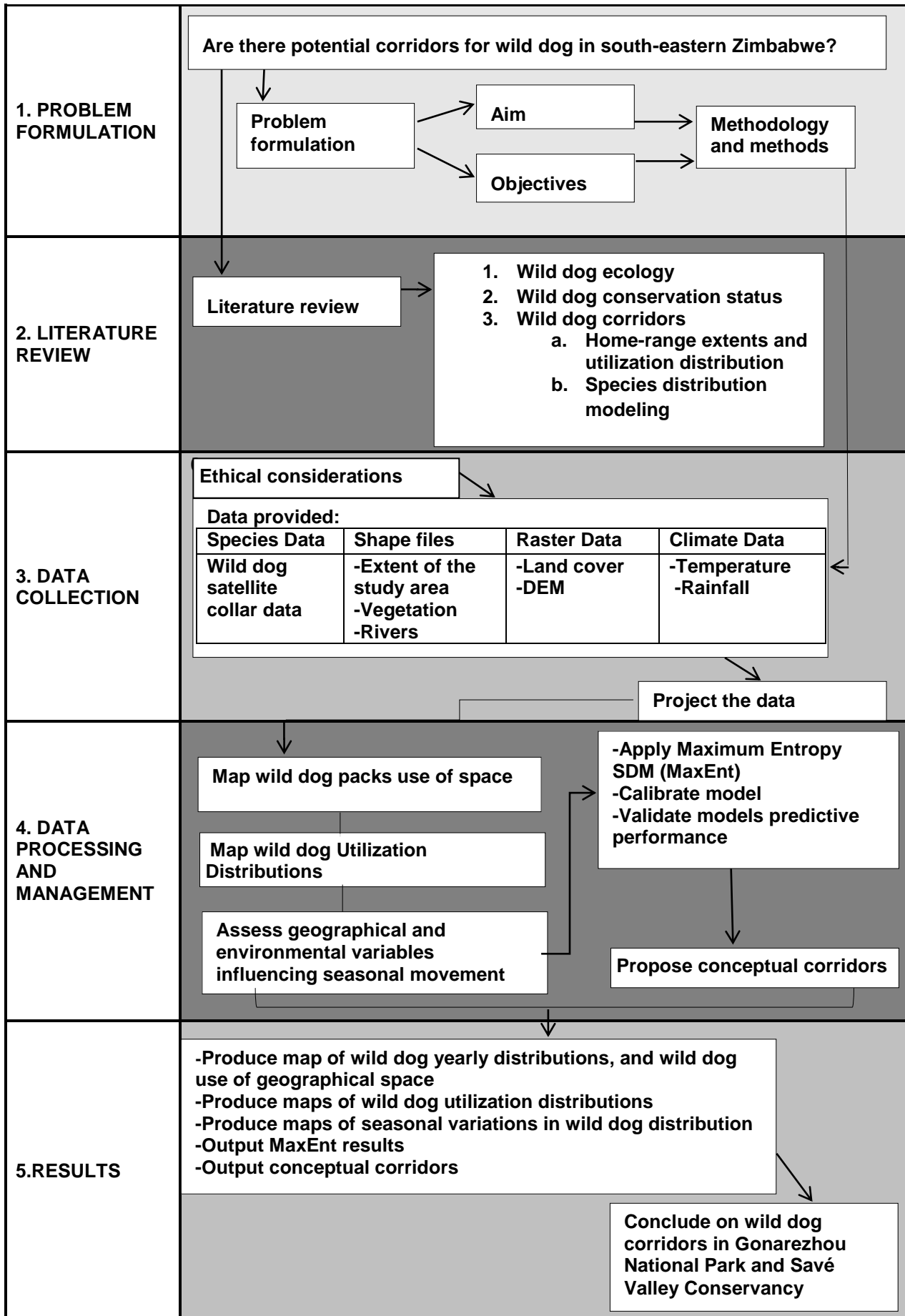


Figure 1.1 Steps followed in chronological order to apply species distribution modelling in identifying ecological corridors for the African wild dog in south-eastern Zimbabwe.

1.7 THESIS STRUCTURE

Chapter one is an introductory chapter to the whole study. It presents the background and focus of the research through the problem statement, significance, aims and objectives and a detailed research design with the steps followed to conduct the research.

Chapter two documents the six-tier review of literature the study focused on. The literature review topics were namely, wild dog ecology, conservation status, corridors, movement and connectivity, UD mapping and modelling probability distribution using SDM. Reviewing the literature laid the foundation for the methodology and methods that were applied the study.

Chapter three comprises a detailed account of the methods used in the study from data collection, preparation and processing. These included using wild dog satellite data with the study areas' data to map dens, UDs, assess biotic and abiotic variables affecting wild dog and model wild dog probability distribution.

Chapter four through to six outline the study's results and discussions. Chapter four explores wild dog den locations and durations. Chapter five gives the results of the differences between UDs for packs as well as males and females in different seasons. Chapter six reports the trends found in the biotic and abiotic variables that influence wild dog movement and distribution patterns. This chapter also presents wild dog probability distribution models outside GNP and SVC.

Chapter seven concludes the study by highlighting key observations, strengths and shortcomings of the study and re-visiting the study's objectives. Thereafter, the chapter evaluates the study and makes recommendations to conservationists on the wild dog corridors and applicability of the methods used to map them to assist in the conservation of wild dogs.

CHAPTER 2: CAUSES AND POSSIBLE SOLUTIONS FOR AFRICAN WILD DOG CONSERVATION

“If the value and worth of wild dog was understood by all, there would be more effort towards conserving this amazing carnivore in Zimbabwe” (Nyathi 2013, Pers com). Nyathi, who is a conservation club coordinator for the Painted Dog Conservation Project in Hwange, Zimbabwe, illustrates how important it is to conserve the endangered wild dog in Zimbabwe. The primary cause of declining wild dog populations is the loss of their habitat (Mbizah et al. 2014) made worse by secondary factors that limit their movement such as predation (Darnell et al. 2014). The Canid Taxon Advisory Group states that five factors considered to influence wild dog are habitat, food, behaviour, sensory and social characteristics (Cloutier & Packard 2014). Wild dog experience highest risk from threats during their movement because of their complex pack based ecology (Whittington-Jones, Parker & Davies-Mostert 2011; Hunter et al. 2014). Implementing wild dog corridors promotes safer movement and dispersal (Beier, Majka & Newell 2009; Pittiglio et al. 2012) and in turn, enhances the survival and increase of the species population (Lin 2008; Caro et al. 2009).

Wild dog are a keystone species, because they are apex predators that require large spaces to persist (Woodroffe & Sillero-Zubiri 2012; Cloutier & Packard 2014). Although wild dog being present in an area does not guarantee the presence of other species, their absence is a representation of low biodiversity (Morrison et al. 2007). For example, wild dog have a hunting accuracy of 70 to 95% (Kratt & Kratt 2013) such that their declining population is leading to the reduction of their prey species ranges (Morrison et al. 2007). Therefore, planning for wild dog conservation facilitates conservation of other species (Woodroffe et al. 2007; Beier, Majka & Newell 2009; Beger et al. 2010; Jachowski et al. 2010; Rasmussen & Macdonald 2011). Whilst it is difficult to measure “effectiveness” of reserves, studying species and their habitats can help investigate reserves spatial characteristics (Chape et al. 2006). This review discusses the African wild dog, its conservation status and how corridors for the species can be identified in south-eastern Zimbabwe.

2.1 THE AFRICAN WILD DOG (*LYCAON PICTUS*)

The African wild dog previously belonged to the genus *Canis* together with other predators such as jackals and wolves (Rasmussen & Macdonald 2011). However, African wild dog diverged from the generic canid ancestor some number of years ago (Marsden et al. 2011) into the genus *Lycaon* (Marsden et al. 2009). *Lycaon* has a unique evolutionary lineage not related to domestic dog (Flacke et al. 2013). Wild dog coats are characterised by a unique tri-coloured pelage of tan, black and white (Leigh 2005) and each individual has a unique coat pattern (Davies-Mostert et al. 2012). These predators have rounded and unusually large black ears (Marsden et al. 2009) and four toes on the foreleg (Woodroffe et al. 2007), which is unlike the other canid species that have a vestigial claw (Rasmussen & Macdonald 2011). It is common to observe morphological and genetic variation in this species across its geographic range (Marsden et al. 2011). Wild dog are medium-sized with a weight of between 18 to 34 kg (Burrows 2011) and an average shoulder height of 60 to 75 cm (Hayward et al. 2007). Over the years, wild dog have evolved physiological adaptations such as sharp claws and long legs (Marsden et al. 2009) to suit their specialised niche as a carnivorous hunter (Mills & Gorman 1997). They are highly social, group-living canids (Becker et al. 2012) that live in packs of two to thirty adults and yearlings (Woodroffe et al. 2007; Davies-Mostert et al. 2012). Wild dog are cooperative breeders such that the larger the pack size, the healthier each individual dog is (Gusset & Macdonald 2010). One ecological wild dog process that influences their chances of increasing population is denning (Kratt & Kratt 2013).

2.2 CONSERVATION STATUS

Some authors suggest that from the 34 sub-Saharan countries in which wild dog used to exist, viable populations now remain in seven countries (Marsden et al. 2009; Burrows 2011), whilst other authors suggest wild dog are now extinct in 25 of their original 39 countries (Whittington-Jones, Parker & Davies-Mostert 2011; Rasmussen & Macdonald 2011). Nonetheless, wild dog have exhibited severe population declines in their distribution throughout Africa (Davies-Mostert et al. 2012) and are in the endangered category of the IUCN Redlist (Woodroffe & Sillero-Zubiri 2012). The largest remaining populations are confined to southern Africa (Becker et al. 2012), particularly in Zimbabwe where there is need for targeted management and wild dog conservation practices within reserves (Lindsey et al. 2011). In Zimbabwe, the largest population around 1997 was in the Zambezi Valley, with secondary populations in Hwange National Park and associated conservation

areas (Rasmussen 1997). However, currently the largest populations are in the south-east low-veld (in Gonarezhou National Park (GNP) and Savè Valley Conservancy (SVC)) and the Zambezi Valley, with a smaller population in Hwange (Groom 2013a, Pers com).

2.2.1 Main causes of declining populations

Wild dog occupy a diverse range of habitats including short-grass plains, semi-desert, bushy Savannas, and upland forest (Woodroffe et al. 2007; Lindsey et al. 2011; Rasmussen & Macdonald 2011; Woodroffe & Sillero-Zubiri 2012). This is advantageous as the wider the range of habitats they can inhabit, the more adaptable it makes them. However, in sub-Saharan Africa, wild dog have had to contend with habitat fragmentation and loss (Marsden et al. 2009) as the primary cause of the global decline of populations and species (Chape et al. 2006) and a threat to wild dog persistence (Whittington-Jones, Parker & Davies-Mostert 2011). Habitat fragmentation is the discontinuities that exist in previously continuous habitat resulting in distinct land stretches of differing habitat (Bennet & Saunders 2010), whilst habitat loss is the disappearance of suitable areas for a species to persist (Pressey & Bottrill 2009). Both are landscape-level processes such that fragmented landscapes have differing shapes and sizes in geographical space (Woodroffe & Ginsberg 1998). Changes in the landscape affect species through altering patterns of occurrence as well as processes that influence the distribution and viability of the species (Bennet & Saunders 2010). As a response to habitat fragmentation, practices such as reserves expansion, improving habitat quality, increasing connectivity, and planning for the long term can be influential in reducing habitat fragmentation (Karanath & DeFries 2010).

Due to their nomadic behaviour, wild dog are highly susceptible to different threats and three of these are the major causes of their declining populations (Swanson et al. 2014). Firstly, loss and lack of pristine habitat is the major cause of wild dog declining populations (Woodroffe et al. 2007; Angulo et al. 2013). This is due to wild dog pack dynamics, such that they do not practice inbreeding (van der Meer et al. 2013) and adult males and females are exposed to high rates of mortality when they emigrate to form new packs (Leigh 2005, Kratt & Kratt 2013). Human influences (Davies-Mostert, Mills & Macdonald 2013), human-wild dog conflict (Mbizah et al. 2014), and the presence of roads (Andrew, Wulder & Coops 2011) factor into the loss of habitat. Secondly, infectious disease particularly rabies from domestic dogs is another cause of declining

populations (Woodroffe & Ginsberg 1998; Bennet & Saunders 2010; Flacke et al. 2013). Therefore, presence of domestic dogs on the periphery of natural habitats interferes with wild dog spatial distribution (Vanak & Gompper 2010). However, Woodroffe & Donnelly (2011) studied contact between wild dog and domestic dogs and found that contact was limited because the domestic dogs were associated with humans that wild dogs avoided. Lastly, predation by larger carnivores particularly lions (*Panthera leo*) (Courchamp, Rasmussen & Macdonald 2002; Vanak et al. 2013) is also a cause of declining populations. This is because they compete for prey (Swanson et al. 2014), are partially responsible for high pup mortality rates (Darnell et al. 2014) and significant adult deaths in SVC are a result of predation by lions (Groom 2013b, Pers com).

2.2.2 Proposed methods to counter population decline

Conservation planning is the decision-making process behind the preservation of decreasing resources to minimize the loss of biodiversity and ecosystem services (Pressey & Bottrill 2009). The planning should include social, economic and political concepts in order to be effectively implemented (Margules & Pressey 2000). The future of wildlife conservation is grounded in how prepared conservationists are to respond to increasing social conflict over wildlife issues (Teel and Manfredo 2009). Therefore, conservationists need tools to address habitat loss, habitat fragmentation, and human-wildlife conflict, which are key issues in wild dog conservation (Marsden et al. 2009). One possible way to address these issues is through setting up reserves (Chape et al. 2006; Büscher & Schoon 2009) as havens for various species from both habitat fragmentation and loss in areas where humans are tolerant of transient species (Andrew, Wulder & Coops 2011). Reserves' role is to separate crucial biodiversity elements from processes that threaten their existence in the wild (Margules & Pressey 2000) and assist in replacing under-utilized areas with features similar to over utilized areas to provide migration opportunities for species (Hunter et al. 2014). Wild dog ecological needs are highly complex (Lindsey et al. 2011) and their habitat choice is influenced by foraging and hunting success (van der Meer et al. 2013) making it difficult to select priority areas that incorporate biological patterns and processes suitable for them (Rouget et al. 2006). However, establishing wild dog corridors between reserves could be vital to their ability to survive while dispersing (Davies-Mostert et al. 2012).

Corridors are beneficial in conservation as an informed approach in maintaining ecological connections; protecting complex ecosystem functions and partitioning landscapes based on reserves (Goldman 2009). Different types of wildlife corridors exist for different species (Beier, Majka & Newell 2009). They are defined by either known movements of animals between two reserves, a proposed connection between important habitats (Caro et al. 2009) or areas that can be used for re-introduction or re-location of species (Hayward et al. 2007). Reserves connectivity and land use influence wild dog corridor planning as well connected areas provide suitable habitat (Hayward et al. 2007) whereas, poorly connected areas multiple landscape types lead to increased wild dog mortality (Bennet & Saunders 2010) and affect the species persistence (Conlisk et al. 2013). Species survival during dispersal is a key factor in determining the persistence of the species (Lin 2008). Based on these factors, in the study wildlife corridors either are areas with suitable habitat for wild dog connecting two or more reserves in order to support their breeding; or are possible locations for re-location.

2.3 WILDLIFE ECOLOGICAL CORRIDORS

In order to effectively reduce and manage the effects of habitat fragmentation on a particular species, characteristics of the species' location as well as biotic and abiotic factors influencing that location should be understood (Marsden et al. 2009). Understanding present and future distribution patterns of threats to species persistence is crucial in focusing conservation resources on areas and features that are endangered (Margules & Pressey 2000). Conservation planning should acknowledge how the world is characterised by dynamic biological processes and threats to biodiversity (Pressey et al. 2007) and DeFries, Karanth & Pareeth (2010) suggest "Zones of Interaction" (ZOI) outside reserves are crucial to species conservation goals. This can be achieved in wildlife conservation planning through assessment and implementation of wildlife corridors (Chetkiewicz & Boyce 2009) which seek to enhance a species' survival amongst other things (Graham et al. 2009; Klein et al. 2009; Pittiglio et al. 2012).

Generally, corridors are beneficial, but also have disadvantages such as incurring management costs through land purchases, fencing, or overpass construction (Whittington-Jones, Parker & Davies-Mostert 2011). Conceptual corridors are areas that presumably best facilitate movement of a keystone species in either one single movement (re-location), or numerous movements over time

(Beier, Majka & Newell 2009). Single movements for wild dog would be for migration to form new packs (Kratt & Kratt 2013) and in search of habitat that provide sufficient ecological resources for survival (Whittington-Jones, Parker & Davies-Mostert 2011; Roever, van Aarde & Leggett 2013). Prey availability (Lindsey et al. 2011) and avoidance of predators (Margules & Pressey 2000; Thaker et al. 2011; Webster, McNutt & McComb 2011) determine numerous wild dog movements.

In addition to the factors mentioned above, the method used to define conceptual corridors should consider movement patterns, and corridor purpose (Andrew, Wulder & Coops 2011). Different methods can be used to establish potential corridors, namely least cost/path analysis (Beier, Majka & Newell 2009; Shannon et al. 2009), circuit theory (Roever, van Aarde & Leggett 2013) and most recently species distribution models (SDMs) (Phillips & Elith 2013; Bucklin et al. 2014). Least-cost corridors are popular models (Chefaoui 2011) developed using a GIS raster of potential resistance a species will face when moving through the landscape (Beier, Majka & Newell 2009). Pittiglio et al. (2012) used least-cost models to determine the influence that environmental and anthropogenic variables had on elephant seasonal distribution predictions and found that altitude; normalized difference vegetation index and distance to water were useful resistance values due to their influence in both the wet and dry seasons. Least-cost's major challenge is deciding how to assign resistances for each variable influencing the species (Taylor, Fahrig & With 2006) as they determine the accuracy in proposed corridors and this challenge was overcome with the introduction of Maximum Entropy (MaxEnt). MaxEnt is an innovative approach that uses jackknife tests to assess the influence (resistances) each variable has on the output (Hernandez et al. 2006; Caryl et al. 2014). Prior to identifying the corridors, studies should understand a species movement and connectivity (Pearson 2011), utilization distribution (UD) (Hunter et al. 2014) and probability distribution should be mapped (Beger et al. 2010).

2.4 WILD DOG MOVEMENT AND CONNECTIVITY

Wild dog movement behaviour is a key component in their vulnerability to extinction (Woodroffe 2010) and can be categorised into two types. Foraging when the wild dog hunt for prey (Koper & Manseau 2009; Mbizah et al. 2014) and flight when the wild dog avoid humans and predators (Austin 2007) both spatially and temporally (Vanak et al. 2013; Darnell et al. 2014). The difference in movement is a result of what Bennet & Saunders (2010) call a "species-centred" interpretation of

the landscape and how the species moves through it in different times and situations. Both movements have different patterns and pivotal influence on the distribution of a species in a landscape. Thiebot et al. (2013) assessed the foraging patterns of penguins (*Eudyptes*) during their post-breeding migration and found that penguins had a temporary reduction of different environmental characteristics at the breeding site, because of an instinctive characteristic of species to search for food. Movement patterns of species in flight are dispersed (Goldman 2009) largely due to the movement being a response to danger. Mollenhauer et al. (2013) did a study to assess the movements of Brook Trout (*Salvelinus fontinalis*) during threats using trackers. Mollenhauer and associates found that whilst the movements were variable, those that occurred during threats led to the fish favouring pools that correlated to their size and stream flow, presumably as a protective measure. While such information is enlightening on species movements, species are adaptive and their characteristics may vary in changing variables for example, different temperatures (Syphard & Franklin 2009; Becker et al. 2012) and in different seasons (Roever, van Aarde & Leggett 2013).

The movement and ecology of wild dog highlight different types of connectivity (Beger et al. 2010) namely, structural/biological and functional/geo-physical (Villard & Jonsson 2009). Biological connectivity is the movement of individuals between habitats diurnally, seasonally, or during their life cycle for feeding or reproduction (Taylor, Fahrig & With 2006). Transfer of energy and matter that occurs during the movement because of gravity, meteorological phenomena, and the water cycle is geo-physical connectivity (Lin 2008). Biological connectivity is influential in preserving biodiversity in wildlife corridors (Cowling et al. 2003; Andrew, Wulder & Coops 2011). Biodiversity is inclusive of the amount (Margules & Pressey 2000) and quality (Pressey et al. 2007) of habitat in an area such that when planning for corridors the amount of habitat available is considered (Pressey & Bottrill 2009) whereas, when maintaining the corridor, the quality of the habitat is considered (Jantke & Scheinder 2010). To understand species movement and connectivity, it is important to acquire the species locality data of where the species already is (Gurrutxaga et al. 2010).

2.4.1 Collecting wild dog locality data

Previously, studying species movement was a cumbersome task (Meyburg & Meyburg 2009) that involved sightings (Wilson, Shepard & Liebsch 2008), descriptions from ranchers (Pierre &

Higuchi 2005) and history spread by word of mouth (Cushman 2010). This posed problems such as over-counting or under-counting (Seegar et al. 1996), repetitive counting (Pierre & Higuchi 2005), and bias in records of species (Meyburg & Meyburg 2009). GPS and satellite collars have made data collection for animals easier (Wilson, Shepard & Liebsch 2008; Cushman 2010; Movebank 2014), and offers improved depth of study of animal behaviour and migration (Meyburg & Meyburg 2009). Collars have problems such as size and weight (Wilson, Shepard & Liebsch 2008; Movebank 2014), battery recharging (Pierre & Higuchi 2005), replacement of dysfunctional collars (Cushman 2010) and limited accuracies in GPS-collars. Nonetheless, the value and quality of data from collars has proved to be fundamental in species studies through higher accuracy in GPS-collars leading to more accurate locations (Wilson, Shepard & Liebsch 2008), facilitating abstract interpretations of animal movement (Seegar et al. 1996) and possible extents of UD's (Getz et al. 2007). One of the main factors in wild dog movement behaviour is their reproducing season in a process called denning (Mills & Gorman 1997).

2.4.2 Wild dog denning

Collar data has helped studies find that wild dog are cooperative breeders (Gusset & Macdonald 2010; Woodroffe & Sillero-Zubiri 2012) where only the alpha male and female dog of a pack reproduce in an ecological process known as denning (Becker et al. 2012). Whilst in each pack, denning strategy focuses on the best possible way to ensure survival of the pups, pup survival rates and litter size vary with pack size where larger packs have larger litters and higher pup survival (Gusset & Macdonald 2010). Den locations are chosen mostly to protect pups from predators (Lindsey et al. 2011) such that dens are commonly underground or in caves with sandy soils (Whittington-Jones, Parker & Davies-Mostert 2011), and in areas with thick thicket vegetation (Courchamp & Macdonald 2001). Majority of dens are in areas of lower prey density (Mills & Gorman 1997; Mbizah et al. 2014) and occasionally found near standing water, which the alpha female needs during lactation (Davies-Mostert et al. 2012). Wild dog can use a den more than once in different seasons or interchangeably in one season (Rasmussen & Macdonald 2011) but, it does not follow that a pack will use the same den every denning season (Woodroffe & Sillero-Zubiri 2012). During denning seasons, movement is clustered compared to wide-ranging movement in non-denning seasons (Romañach & Lindsey 2007; Webster, McNutt & McComb 2011) illustrating that denning is influential in wild dog movement and distribution patterns (Lindsey et al. 2011).

Duration of denning season is not for a fixed period (Groom 2013a, Pers com) and varies with location and habitat (McNutt & Silk 2008) but is necessary to understand wild dog ecology. Burrows (2011) found that packs in Selous and Ruaha denned in the dry season when there was prey clustered around water and in the wet season in Serengeti when there was abundant temporary water supplies and other species producing their young as easy prey. In south-eastern Zimbabwe (GNP and SVC), denning usually occurs in the cold and dry season when dens are not prone to flooding and presumably to take advantage of less thick vegetation which allows easier hunting (Buettner et al. 2007; Groom 2014, Pers com). Denning influences the way wild dog temporal distribution and how they are distributed in their geographical space (Becker et al. 2012; Angulo et al. 2013).

2.5 WILD DOG UTILIZATION DISTRIBUTION

Species distribution depends on areas with suitable biotic and abiotic variables accessible to the species for use in its habitat. It is important to understand wild dog space-use patterns (Jachowski et al. 2010; Hunter et al. 2014) and update their range extent map (DeMatteo & Bette 2008). The ecological niche theory defines two categories of distribution namely potential and actual distribution (Pearson 2011). Potential distribution (fundamental niche) is the landscape that a species is able to utilise based on its abiotic and biotic requirements (Soberón & Peterson 2005; Syphard & Franklin 2009). Actual distribution (realised niche) is the landscape that the species is occupying in reality and is a subset of the fundamental niche limited by the species' dispersal abilities or a barrier (Soberón & Peterson 2005). It is unrealistic to expect studies to predict the full extent of either the actual or the potential distribution of species (Pearson 2011). However, both distributions are fundamental for conservation planning (Araújo & Guisan 2006). Buisson et al. (2009) advised that species' distribution and movement are co-dependent in studies for efficient conservation planning (Buisson et al. 2009). A home-range is the geographical space an animal uses as habitat and for movement (Bauer 2003; Cumming & Corneils 2012) whereas a UD is the geographical distribution an animal is assumed to use based on GPS data collected from the animal over time (Pearce & Boyce 2006; Cumming & Corneils 2012).

UDs are mapped using the species presence-only (locality points over a period of time) data relative to actual distributions (Bauer 2003) that are a representation for the area used for hunting, mating

and caring for young (Getz et al. 2007). Occasional additional areas visited in flight from predators for example, should not be analysed as part of the UD (Hayward et al. 2009; Cumming & Corneils 2012). UDs are useful when species records are available, but environmental predictors and biological understanding are scarce (Pearce & Boyce 2006). The UDs include species presence points to define the species' range boundary (Svenning et al. 2011) using a geographical mapping method to show the species' home-ranges (Hayward et al. 2009). Different techniques to map UDs discussed in literature include maximum polygon (MP), minimum convex polygon (MCP) and kernel density estimation (KDE). In addition, there has been different software created to map UDs of animals (Getz et al. 2007) such as Calhome 1994, HomeRange 1996, KernelHR 1997, adehabitat 2006 and GME 2012. Cumming & Corneils (2012) did a study to compare the performance of home ranging techniques for ducks and African buffaloes based on the receiver operating characteristic area under the curve (ROC AUC). The study found that whilst the MP and MCP techniques drew bounding polygons around the species points they included additional space in the UDs that the species did not actually use. KDE attempted to draw a polygon around only the area that the species used and provided the best results incorporating ecological components that are statistically valid.

Getz et al. (2007) added to the MCP method using a nonparametric kernel method and found that it delineates UDs that are more definitive. This further illustrates the superiority of a kernel approach, complimented by Pebsworth, Morgan & Huffman (2011) who also did a study to compare the different UDs techniques on GPS collar data from chacma baboons and made similar conclusions. Wild dog have large UDs primarily due to their wide-ranging behaviour (Romañach & Lindsey 2007; Woodroffe 2010; Webster, McNutt & McComb 2011; Cloutier & Packard 2014). In most reserves, wild dog move long distances in search of mates and this has had influence on the size of their UDs (Leigh 2005). Woodroffe (2010) mapped wild dog home-ranges using KDE and found that they provided detailed estimates of their UD and that UD extent differed between males and females because of variation in prey density (Herfindal et al. 2005). Therefore, KDE is a useful geographical method to use to map UDs for species (Getz et al. 2007; Pebsworth, Morgan & Huffman 2011; Cumming & Corneils 2012). However, the kernel methods failed to converge to the true area represented by data as species locality points increased (Getz & Wilmens 2004) and failed to describe temporal characteristics of the UDs such as rates of re-visitation to locations and durations of stay at different locations.

Lyons and associates addressed the shortfalls of the traditional UD methods with the introduction of Time Local Convex Hull (T-LoCoH) in 2013, which works with time stamped locations to explore species movements. T-LoCoH creates minimum convex polygons around each of the locations called hulls as its unit of analysis to delineate UDs, re-visitation rates, and durations of stay (Lyons, Turner & Getz 2013). It uses a Scaling Parameter (S) to calculate a Time-Scale Distance (TSD) and a Maximum Theoretical Distance (MTD). S controls how local the hulls are in time and space, and ensures 40 to 80% of the hulls are time-selected. TSD calculates the distance between locality points and uses MTD to calculate the temporal distance. Each species ratio between TSD and MTD identifies nearest neighbours that create isopleths. Isopleths are contour lines that define a subset of locality points based on the probability of occurrence. Finally, T-LoCoH calculates re-visitation as the number of times a species visited an area inside the hull and duration of stay as the average number of points in the minimum convex hull (Lyons, Turner & Getz 2013).

2.6 MODELLING WILD DOG POTENTIAL DISTRIBUTION

Conservation planning for wildlife has become a crucial issue in recent years (Gordon et al. 2009) because incorrect species' range predictions may promote spatially flawed conservation efforts (Seo et al. 2009; Sypard & Franklin 2009). The failure of conservation plans to include focus on the representation as well as occurrence of a species in reserves (Pressey et al. 2007) has been one of the main challenges because species and habitat types represent measures of biodiversity (Rubio & Saura 2012). Therefore, species location, movement and distribution identifies conservation needs (Jantke & Scheinder 2010) and if plotted can identify similarities and differences among reserves (Margules & Pressey 2000; Büscher & Schoon 2009). Furthermore, the niche theory states that each species have ecological requirements, which the species cannot persist outside of (Villard & Jonsson 2009). A suggested approach to overcome exclusion of species from conservation plans whilst considering the niche theory is through SDM (Chefaoui 2011; Conlisk et al. 2013) used to estimate species ranges in conservation planning and in identifying potential range shifts (Seo et al. 2009). Four crucial components in SDMs are species data, scale and sample size, variables influencing the species, model used, and its validation (Soberón & Peterson 2005; Elith et al. 2006; Elith & Graham 2009; Klein et al. 2009; Epps et al. 2011).

2.6.1 Presence-only, presence-absence and pseudo-absence data

Data used in species studies can be presence-only (DeMatteo & Bette 2008) or presence-absence (Chefaoui 2011) data. Quality and quantity of species distribution data available is important in SDM (Klein et al. 2009; Svenning et al. 2011). As a guiding principle, species data should consider whether the species has a balance between biotic interactions and dispersal ability and how well each sample represents the species in its occupied niche (Pearson 2011). Presence-only and presence-absence data have different functions in conservation planning (Conlisk et al. 2013), and this has bearing on the SDM chosen for a study (Roever, van Aarde & Leggett 2013). Presence-only data plays a fundamental role in SDMs (Elith & Leathwick 2009; Franklin et al. 2009) but has holes and corners showing high use areas that affect SDM results (Getz & Wilmens 2004). On the other hand, different algorithms used to estimate fundamental niches require information on absences of species in a study area (Soberón & Peterson 2005). Elith et al. (2006) compared the predictive ability of different SDMs using only occurrence data and found that presence-only data were effective for modelling species distributions but other conservation questions still require absence data (Elith et al. 2006). It is difficult to obtain confirmed absence data and many researchers advocate the use of pseudo-absences of species based on presence data (Araújo & Williams 2000; Sypard & Franklin 2009; Lobo, Jiménez-Valverde, & Hortal 2010). The method used to deal with the pseudo-absences impacts ecological conclusions (Hertzog, Bernard & Jay-Robert 2014) such as over-prediction (Chefaoui 2011) and more spread out absences compared to the realised distribution (Lobo, Jiménez-Valverde, & Hortal 2010). None the less, pseudo-absences are more accurate when selected from a sampling bias grid (Hertzog, Bernard & Jay-Robert 2014). Presence-only, presence-absence and pseudo-absence data depend largely on the models' scale and data's sample size (Jiménez-Valverde 2012).

2.6.2 Scale and sample size

Whilst SDMs are often in studies using large grid sizes (Elith & Leathwick 2009), species respond to habitat at different spatial scales (Hollard, Bert & Fahrig 2004) such that it is important to understand what the study's modelling aim is before selecting a suitable scale. There is no consensus on scale and/or sample size and ecologists require multiple tests to evaluate the impact of sample size on ecological studies (Goldman 2009). Seo et al. (2009) evaluated a range of scales and

model types and their results showed that operational scale is influential in the running of SDM's, with the selection area increasing significantly, when models are on larger grid cells. It is important to quantify modelling algorithms to sample size because of data availability limitations (Singh et al. 2013) and because location and scale influence the perception of patterns (Mellin et al. 2014). However, sampling species data is expensive and difficult such that deciding on suitable scales for studies is difficult (Wisniewski et al. 2008b). In addition, sampling frequency and duration affect collected data because infrequent samples have higher spatial errors compared to frequent samples (Johnson & Ganskopp 2008; Wilson, Shepard & Liebsch 2008). Stockwell & Peterson (2002) found that the average success rate of predicting species occurrence at a location was 90% of the maximum within 10 sample points and was near 100% at 50 data points. General consensus is that neglect of ecological knowledge is a limiting factor in statistically modelling probable species distributions (Austin 2002) but suitable scales for conservation planning are difficult to decide (Singh et al. 2013). Hollard, Bert & Fahrig (2004) assessed spatial scales that beetles responded differently to various environmental variables and found that the range was between 20 to 2000 m illustrating the best spatial scale depends on the study's aim. Sample size is fundamental in evaluating SDM results. Wisniewski et al. (2008b) evaluated 12 different algorithms with independent data from 46 species with three sample sizes and found that with decreasing sample size, model accuracy decreased and variability increased across species and between models. Therefore, novel methods performed better at larger sample sizes whilst models such as maximum entropy (MaxEnt) had the best predictive power across all sample sizes (Hernandez et al. 2006). The scale and sample size keys in with biotic and abiotic variables used in the study as predictors of the species movement and distribution pattern (Conlisk et al. 2013).

2.6.3 Variable selection

Suitable environmental variables for species can be identified using either mechanistic or correlative approaches (Goldman 2009) depending on the species (Araújo & Guisan 2006). Mechanistic approaches define a species' tolerance to environments using physiological limits (Araújo & Williams 2000) which is difficult to determine for adaptive species such as wild dog (Caley, Tennant & Hood 2011). Correlative approaches estimate suitable environments for a species using known occurrence records and environmental variables likely to affect the species population and survival (Elith & Graham 2009) such as rainfall and predation for wild dog (Lindsey et al. 2011). Due to their consideration of species distributions and movements (Buisson et al. 2009),

which facilitate habitat selection (Elith et al. 2006) correlative approaches are more suitable for wild dog. Apart from the species locality data, SDMs also consider biotic and abiotic correlates to species distributions (Austin 2007). Bucklin et al. (2014) assessed the usefulness of contributing climatic predictors with additional types of environmental predictors in SDM and found that no one-predictor set produced significantly more accurate models. Studies on threats to wildlife persistence show that threats include both anthropogenic and natural factors which can be either biotic or abiotic (Epps et al. 2011). Pressey et al. (2007) draws attention to how both abiotic and biotic factors affecting a species are important in conservation planning. Whilst this is more applicable to plants, such factors can also affect animals either directly or indirectly (Caley, Tennant & Hood 2011). Svenning et al. (2011) concurs with Zimmerman et al. (2010) that different types of predictors can be included in studies and emphasized how both biotic (interactions and dispersal) and abiotic (environment) factors are important. Abiotic factors include light, water, temperature, carbon dioxide, oxygen, nutrients, and fire and biotic factors are interactions that a species has with other organisms in its ecosystem. Abiotic factors define the “tolerance limits” of a species namely where the species can survive, where it has ecological stress, and where it is completely absent. Teel & Manfredo (2009) summarize interactions as mutualism, predation, competition, commensalism, amensalism and neutralism and state that each relationship dynamic affects the species either positively, negatively or has no impact. This study looks at three biotic variables discussed in Section 2.6.3.1 and five abiotic variables discussed in Section 2.6.3.2.

2.6.3.1 Biotic variables

Wild dogs are persecuted mostly because they are assumed to predate on livestock (Kissui 2008) and to displace the prey they hunt from the vicinity of their home-range (Mbizah et al. 2014). On the other hand, human influences affect prey-predator relationships (Davies-Mostert, Mills & Macdonald 2013) and features such as roads enhance habitat fragmentation (Andrew, Wulder & Coops 2011). Gusset et al. (2009) assessed human-wildlife conflict in Botswana focussed on predation of livestock by wild dog and other carnivores. Gusset and associates found that predator attacks are of concern to farmers because of their economic threat due to loss of livestock. However, the study showed that wild dog were responsible for only 2% of predator attacks and largely survived on wild prey. Woodroffe et al. (2007) analysed rates and causes of mortality in eight wild dog populations’ inside and outside reserves, and found that persecution was largely by humans. Human influences are not always negative for wild dog as they do eat carcasses from hunts

at a distance of two and three kilometres away from farms at dawn and dusk (Forsyth et al. 2014). Therefore, methods that are used to solve human-wild dog conflict should counter the general belief that wild dog are “vermin” (Whittington-Jones, Parker & Davies-Mostert 2011; Mbizah et al. 2014) through practices such as increased lookouts for livestock during day and night (Gusset et al. 2009), anti-poaching efforts and incentivising wildlife tourism activities for locals. In addition, further study to provide development of appropriate conservation strategies (Lindsey et al. 2011) and promoting formation of conservancies where neighbouring landowners remove boundary fences to create larger continuous wildlife areas (Romañach & Lindsey 2007) can also be done.

Wild dog can navigate across vast expanses of fragmented and human-altered landscapes (Lindsey et al. 2011) and occasionally move outside reserve boundaries. At the protected area edges, wild dog packs especially the smaller ones (Becker et al. 2012; Davies-Mostert et al. 2012), are at higher risk from human activities such as vehicle collisions, direct persecution (Whittington-Jones, Parker & Davies-Mostert 2011) and wire-snares (Courchamp & Macdonald 2001) that are not meant for them (Gusset et al. 2009). Several factors may interact to increase the probability of wild dog leaving reserves (Woodroffe & Ginsberg 1998; Marsden et al. 2009; Rasmussen & Macdonald 2011). These include hunting for prey (Mbizah et al. 2014), looking for mating partners (Cloutier & Packard 2014) and searching for denning sites (Woodroffe & Ginsberg 1998). Therefore, another biotic variable that influences wild dog movement and distribution patterns is the presence of reserve boundaries (Frantzen, Ferguson & de Villiers 2001).

2.6.3.2 Abiotic variables

Wild dog pack fitness depends on prevailing ecological conditions (Gusset & Macdonald 2010) including elevation, water, vegetation, rainfall, and temperature. Whilst previously, elevation was not considered as a predictor of wild dog movement and distribution patterns because of their wide-ranging behaviour, Jackson et al. (2014) found that wild dog prefer to use areas of rugged terrain for denning. As such, elevation influences wild dog movement during their denning seasons. Even though wild dog usually stay away from rivers or use them strategically in order to avoid lions and other large predators, they do need water for lactating females (Davies-Mostert et al. 2012) (Woodroffe & Sillero-Zubiri 2012). Vegetation density influences wild dog movement and distribution patterns in that it is easier to hunt in less dense vegetation (Bauer 2003; Becker et al.

2012). To understand species biotic and abiotic requirements, it is necessary to assess correlations between the species movement and distribution with rainfall and temperature in its habitat (Wisz et al. 2008a; Roever, van Aarde & Leggett 2013). With wild dog, rainfall and temperature presumably influence den locations (Groom 2014, Pers com). Rainfall is not a major factor for wild dog as they can get their water requirements from prey's blood (Becker et al. 2012). However, rainfall totals affect pups' survival where Buettner et al. (2007) found that pup survival was higher following dryer seasons where less vegetation had led to weaker prey and easier kills for wild dog. Temperature is also not a major factor for wild dog as their thermoregulation allows them to easily control their body temperatures (Groom 2014, Pers com) but, it does affect their prey (Woodroffe et al. 2007). Definition of biotic and abiotic drivers of species distributions determines their influence on the SDM's output (Caryl et al. 2014).

2.6.4 Model selection

Geographically weighted regressions assign spatial weights to variables and efficiently investigate spatially varying species-environment relationships (Mellin et al. 2014). However, spatial weights in other methods identify only non-linear relationships. This shows the importance of prior knowledge on methods and their effect on different data because there are numerous data types, approaches, and research questions (Elith & Graham 2009; Gusset & Macdonald 2010). Numerous SDM are available (Elith et al. 2006; Austin 2007; Elith & Graham 2009; Zimmerman et al. 2010; Epps et al. 2011; Roever, van Aarde & Leggett 2013) each with different advantages and disadvantages in ecological studies (Ferrier et al. 2002; Guisan & Thuiller 2005; Araújo & Guisan 2006; Elith & Leathwick 2009). The appropriateness of a SDM for a study depends on the species data, biotic and abiotic drivers, and the SDM's advantages and disadvantages (Araújo & Guisan 2006; Chetkiewicz & Boyce 2009; Svenning et al. 2011). Studying different SDM has given insight into the methodology used for different models such as BIOMOD, GAM, GLM, MaxEnt, rule-set prediction, boosted regression trees, and generalized dissimilarity models (Phillips & Dudík 2008; Kearney & Porter 2009; Elith et al. 2011). Resource Selection Functions (RSF) such as MaxEnt, that map habitat suitability for a species in order to understand the landscape as it is understood by the species (Bennet & Saunders 2010) can be used to analyse seasonal changes in habitat use. RSFs use forage and habitat use patterns (Smulder et al. 2010) and the physical characteristics of the habitat (Chetkiewicz & Boyce 2009). In addition, RSFs assess connectivity between habitats (Roever, van Aarde & Leggett 2013) such that MaxEnt can identify additional

habitat for a species (Zimmerman et al. 2010). Model selection depends on the models evaluation including strengths, weaknesses (Koper & Manseau 2009).

2.6.5 Model evaluation

Heedless of all the progress SDMs have made in the past decade or so, they still have shortcomings such as low performance at small spatial scales (Zimmerman et al. 2010) and assuming balance between species and the environment (De Marco, Diniz-Filho & Bini 2008). In addition, the models omit narrow ranging species due to statistical constraints (Platts et al. 2014) and possess sequential autocorrelation (Koper & Manseau 2009). However, there are solutions to these criticisms such as using restricted dispersal for spatially autocorrelated environmental conditions and statistical k-fold cross-validation (De Marco, Diniz-Filho & Bini 2008). The main criticism for SDM is lacking application in conservation planning (Elith & Leathwick 2009) which highlights the need for conceptual integration in addition to statistical basis in SDM. Application in conservation planning is a challenge because the main consideration of the ecological niche theory is the interplay between geographical space and environmental variables (Soberón & Peterson 2005), as well as their accessibility to the species (Roever, van Aarde & Leggett 2013).

SDM are useful for estimating species' geographical ranges, identifying suitable habitats for species and recognizing primary factors affecting species distribution (Chefaoui 2011) but, due to the criticisms given above and the fact that numerous SDM are now freely available, evaluation of model outputs is necessary (Jiménez-Valverde, Lobo & Hortal 2008). Model evaluation should be done considering relationships between species and the environment; predicting landscape suitability for a species in both the realised and potential niche (Elith & Graham 2009; Franklin et al. 2009) and the method a model uses (Langford, Gordon & Bastin 2009; Franklin et al. 2009). Generally, models which use both biotic and abiotic variables provide more robust predictions (Marmion et al. 2009) and accuracy for species with small geographic range and limited environmental tolerance is greater (Hernandez et al. 2006). Therefore, Bach et al. (2009) suggests using VORTEX, a stochastic population simulation model to evaluate possible areas for re-location of wild dog as they have a large geographic range.

Differences between SDMs depend on the accuracy of a method (Wisniewski et al. 2008b; Elith & Leathwick 2009). Araújo & Williams (2000) determined accuracy of three models based on their ability to map species occurrence. Model A considered the relationship between the species and the environment, model B considered the geographical occurrence of the species and model A + B considered the interaction of both. The study concluded that model A + B performed the best to describe the species occurrence confirming that the best way to assess effectiveness of SDM in conservation is through cross-validation of results (Hernandez et al. 2006; Gusset et al. 2009). Models can also be evaluated using a model evaluation tool called ROC AUC whose output is calculated using training and test data from historic locations of a species (Rakotomamonjy 2004; DeMatteo & Bette 2008). Phillips & Dudík (2008) assessed the validity of MaxEnt in ecological studies using ROC AUC on training data and logistic regressions and concluded that statistical methods ensure validity of the model and are robust as they are repeatable. However, ROC AUC must be used with caution (Peterson, Papes & Soberón 2008; Lobo, Jiménez-Valverde, & Hortal 2010) because independence of ROC AUC from the threshold is irrelevant in practice, as ROC AUC assumes nothing about the effect errors of commission and omission have on the model (Rakotomamonjy 2004; Jiménez-Valverde 2012).

SDM are useful in that they can determine species distribution with advantages to other techniques (De Marco, Diniz-Filho & Bini 2008). MaxEnt is consistently outperforms other methods in correlating the geographical use of space by species (Guisan & Thuiller 2005; Elith et al. 2006; Wisniewski et al. 2008) and their environmental needs (Austin 2007; Elith & Graham 2009; Elith & Leathwick 2009; Zimmerman et al. 2010). In addition, MaxEnt works well with small sample sizes (Zimmerman et al. 2010; Chefaoui 2011) and uses presence-only data (Austin 2007; Phillips & Elith 2013). In addition, MaxEnt works well when there are no confirmed species absences (Phillips & Dudík 2008) and considers statistical accuracy by using graphs that show analysis of omission/commission and ROC AUC (Hernandez et al. 2006).

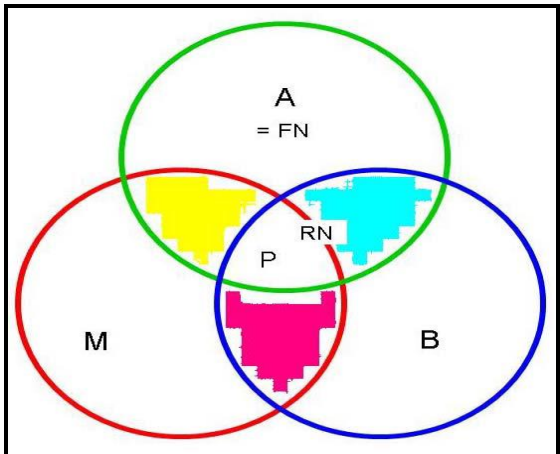
2.7 CONCLUSION

Conservation planning efforts for wild dog as a keystone species in Zimbabwe are progressing, and in turn, the ecological and spatial needs of other species are partially covered. However, further attention is required to ensure sufficient conservation interventions. One way to support

conservation planning for wild dog is by ensuring that they have connectivity between suitable habitats by suggesting conceptual corridors or identifying sites for their re-location. Outlining wild dog UDUs using T-LoCoH, identifying their dens, assessing variables influencing their movement and distribution pattern and mapping their probability distribution with MaxEnt identifies conceptual corridors and re-location sites. The review summarized wild dog ecology and suitable methods to identify additional areas for wild dog habitat.

CHAPTER 3: ECOLOGICAL MODELLING TO SUGGEST WILD DOG CORRIDORS

Wild dog major threat is currently fragmentation and loss of habitat (Rasmussen & Macdonald 2011; Groom 2013a, Pers com; Kratt & Kratt 2013). It is important to identify areas with suitable habitats where the species can survive either to facilitate connections between reserves, or to serve as sites for wild dog re-location. Modelling species requires an ecological theory, a data model, and a statistical model (Austin 2002). The data is species locality points such as wild dogs' satellite collar data and the statistical models explore the ecological theories such as BIOMOD and MaxEnt (Jiménez-Valverde 2012). The ecological niche theory determines the analysis of a species movement and distribution pattern (Figure 3.1). This theory is based on how species are conscious of geographical and environmental space. The geographical space is the location of the species (Kearney & Porter 2009) and the environmental space is a conceptual area outlining the species biotic and abiotic needs. Geographical and environmental spaces are determined by spatial and environmental variables respectively the species positively responds to (Elith & Graham 2009).



Source: Soberón & Peterson (2005:3)

Figure 3.1 Ecological niche modelling concept showing the interaction between biotic and abiotic space for a species

Figure 3.1 Geographic region with appropriate biotic and abiotic factors for the species. B: Region where right combination of interacting species occurs. M: Areas accessible to the species, FN: Fundamental niche which is the space the species are able to survive in. RN: Realised niche which is the space the species are actually present. P: Area with the right environment, is accessible and is within the geographic distribution of the species.

3.1 STUDY AREA

Gonarezhou National Park (GNP) (Figure 3.2) is a large park that spans an area of nearly 5053 km² that is the second largest park in Zimbabwe (Gandiwa & Kativu 2009). This allows GNP to accommodate wild dog populations that as a wide-ranging species require large spaces for ecological activities (Becker et al. 2012). GNP lies at 21° 00' to 22° 15' S and 30°15' to 32° 30' E bordered by the Gaza District of Mozambique (Tafangenyasha 1997) in south-eastern Zimbabwe. The area is generally flat with an altitude between 165 and 575 m and has medium rainfall of 400 to 600 mm annually (Gandiwa et al. 2011) typically in the November to March hot and wet season (Gandiwa & Kativu 2009). GNP's cold and dry seasons runs from April to October (Tafangenyasha 1997; Gandiwa et al. 2011) and has mean monthly maximum temperatures of 25.9°C in July and 36°C in January, and mean minimum temperatures of 9°C in July and 24°C in January (Gandiwa & Kativu 2009). This semi-arid climate supports two major vegetation types namely grassland and woodland (Tafangenyasha 1997; Gandiwa & Kativu 2009) which facilitate easy hunting of prey for wild dog (Buettner et al. 2007).

Savè Valley Conservancy (SVC) (Figure 3.2) comprises key components of the Greater Limpopo Transfrontier Conservation Area (GLTFCA) (Munthali 2007) and lies at 20° 05' S and 32° 00' E (Wolmer, Chaumba & Scoones 2003). SVC spans an area of about 3450 km² (Pole et al. 2004; Davies-Mostert et al. 2012) in south-eastern Zimbabwe and is ranked as one of the largest conservancies in the world (Du Toit 2005) with 24 commercial properties (Wolmer, Chaumba & Scoones 2003). Its size and characteristic gently undulating altitude varying from 480 to 620 m above sea level (Pole et al. 2004; Du Toit 2005) allow it to sustain wild dog populations. SVC has a single hot and wet season from November to March and a long cold and dry season from April to October (Sutmoller et al. 2000; Pole et al. 2004). SVC climate is semi-arid (Pole et al. 2004) with mean annual precipitation of 300 to 500 mm (Pole et al. 2004) which is fairly low and is influential in enhancing wild dog pup survival (Buettner et al. 2007). Temperatures range from maximums of 25° to 27°C (Du Toit 2005) and minimum temperatures that can go below freezing point (Wolmer, Chaumba & Scoones 2003). The vegetation types include deciduous woodland Savanna scattered with rivulet vegetation (Sutmoller et al. 2000).

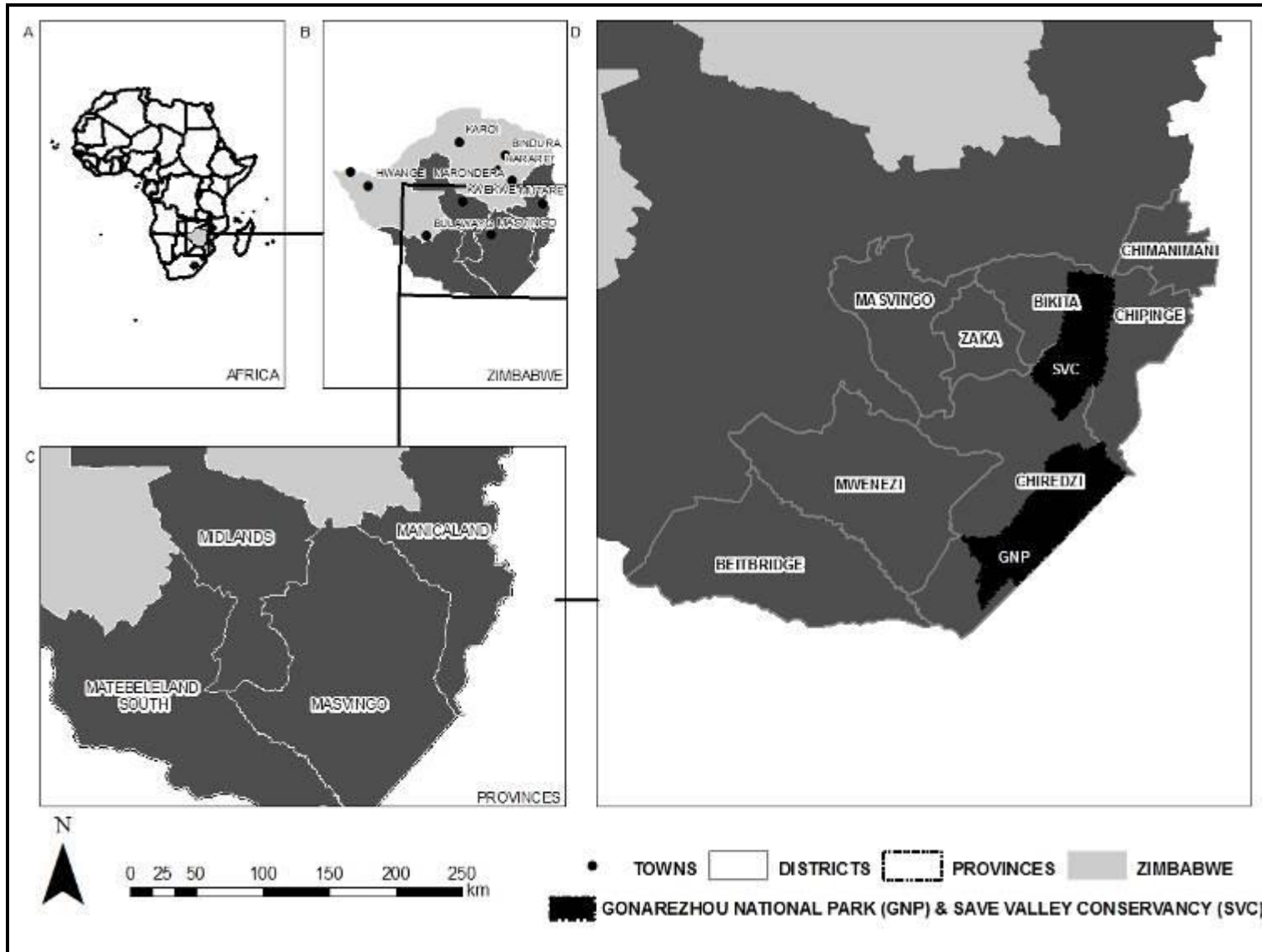


Figure 3.2 Gonarezhou National Park and Savè Valley Conservancy, two reserves in south-eastern Zimbabwe that formed the study areas

3.2 DATA

Appropriate data collection techniques ensure validity and reliability of data used in a research (Mouton 2001). Satellite technology facilitates recording of data measurements made at a distance (D'eon & Delparte 2005) and has since been adapted on animals in collars or tags to aid understanding their movements and distribution patterns (Johnson et al. 2008). In the study, wild dog satellite collar data was the primary data (Mitchell 1999; Tomlinson 2006) complemented by secondary data including human activities, roads, elevation, rivers, vegetation, rainfall and temperature (Chang 2006; Allen 2010). Collar data is qualitative as it shows a species movement and distribution, as well as quantitative as it is sample data of a larger population.

The study was conducted using ArcGIS 10.1 (ESRI 2013), PCI Focus version 2013 (Geomatica 2013), SPSS 22 (SPSS 2014), R console version 3.0.2, R Studio version 3.1.0, Time Local Convex Hull (T-LoCoH) version 1.21, (Maximum Entropy) MaxEnt version 3.3.3k and BIOMOD2 version 3.1-48 software. Correct projected and geographic coordinate systems are important elements of a geographical study (Soechting & Flanders 1992; Wu et al. 2005) as their accuracy (Madej 2001; Maling 2004) determines exact locations of different objects on the earth's surface (Longley et al. 2006). Therefore, all data was projected to Universal Transverse Mercator (UTM) Zone 36S, and geographic coordinate system WGS 1984.

3.2.1 Wild dog ethical considerations

Using animals in a study is sensitive due to their ethical considerations (Cuthill 1991). Collaring of animals includes both field (Smith et al. 2011) and desktop studies (Le Mar & McArthur 2000). Field studies raise concern about collar placement and their impact on the animals (Laurenson & Caro 1994), but desktop studies are not a concern. Collar type does not influence data collection (Smith et al. 2011) and collars do not affect large carnivores both during their placement and over time (Laurenson & Caro 1994). The study verified that African Wildlife Conservation Fund (AWCF) followed ethical procedure during collar placement on wild dog. AWCF does not collar alpha females but rather the largest dog in a pack to avoid disrupting pack dynamics and because no data would be collected during denning seasons when the alpha usually stays at the den

(Courchamp, Rasmussen & Macdonald 2002; Watermeyer 2014, Pers com). Therefore, wild dog ethical considerations were adhered to (Appendix K).

3.2.2 Data Collection

Wild dog satellite collar data was collected for four packs in GNP from 2010 to 2013 (Table 3.1) and nine packs and two individual dog in SVC from 2009 to 2013 (Table 3.2).

Table 3.1 Wild dog packs' collar ID, pack name, sex and the years collared in GNP that were used in the study

Collar ID	Pack Name	Years
AU464	Chalanda	2012-2013
AU466	Machaniwa	2012-2013
Collar ID	Individual Dog Name	Years
AU457	Mabalauta (female)	2010-2011
SAT396	Shangana (male)	2012-2013

Table 3.2 Wild dog packs' and individual dog collar ID, pack name, sex and the years collared in SVC that were used in the study

Collar ID	Pack Name	Years
AU458	Batanai	2011-2013
AU264, AU267	Bedford	2009-2010
AU465	Crocodile	2012-2013
AU262, AU266	Maera	2009-2011
AU558	Mambira	2011-2013
AU263	Mapura	2011-2012
AU452	Nyarushanga	2012
AU559, AU267, AU457, AU557	Splinters	2010-2013
AU263	Star	2009-2010
Collar ID	Individual Dog Name	Years
AU459	Patch (Female)	2011-2012
AU266	Tick (Male)	2011-2013

The study focussed on packs for general patterns and individual wild dogs for differences between male and female wild dogs. This was because the collared dog in a pack occasionally changed due to the collared wild dog dying or a collar malfunctioning (Groom 2013b, Pers com). Consequently, some of collar ID's may appear more than once because they have been reused in the tables. Finally, because collar data can have errors (D'eon & Delparte 2005; Frair et al. 2010; Movebank

2014), it was necessary to remove inconsistencies, redundancies and missing data in the records while vetting the data (Longley et al. 2006; Johnson et al. 2008). This was done using Excel after which the cleaned data was saved as comma delimited (.csv).

Human settlements were digitised as clusters using 2006 to 2007 geo-referenced Google Earth Imagery following Chadil, Rusameesawang & Keeratiwintakorn (2008) approaches because the data could not be secured through other sources. Landsat has been identified as useful in digitising human settlements, but, the 15 m resolution of the imagery after pan-sharpening was too coarse for the study areas where some fields measured two to five meters in northern GNP and one and a half to three metres in southern SVC. However, Landsat 8 scenes (Table 3.3) were used as a visual aid tool for outputs to verify the digitised human settlements and as a background map with band combination 5-6-4. PeaceParks Foundation provided roads, rivers, and vegetation data.

Table 3.3 Landsat scenes ID, path and row, date acquired by sensor used for display in the study

Landsat Scene ID	Path	& Row	Date Acquired
LC81680742013303LGN00	168	74	2014-09-15
LC81680752013303LGN00	168	75	2014-09-15
LC81690742013310LGN00	169	74	2014-10-08
LC81690752013310LGN00	169	75	2014-10-08

The rule of thumb with species studies is that the climatic data should ideally have corresponding dates with the movement data (Seo et al. 2009; Rubio & Saura 2012). This is to understand correlations between the movement and distribution patterns together with prevailing climatic conditions at the time the data was collected (Chefaoui 2011). However, due to a lack of corresponding rainfall and temperature data for the study areas, Worldclim global climate layers with a temporal difference of thirteen years were used. Worldclim data (temperature °C * 10 and rainfall in mm) has a resolution of about 1 km² and was created using interpolations of average monthly climate data from weather stations from 1950 to 2000 (Hijmans et al. 2006).

A comparison of different digital elevation models (DEMs) currently available for Zimbabwe established the appropriate DEM to use for the study. Table 3.4 showed that each DEM has disadvantages such as low spatial, horizontal, and vertical resolution, high spatial inaccuracies, and

partial coverage of the study area (Van Niekerk 2010). Of the compared DEMs, SRTM and ASTER possessed better horizontal accuracies and similar spatial resolutions. Due to SRTM's higher vertical accuracy, it was used in the study. Both study areas are not topographically complex such that any errors present in the DEM would not significantly affect the model outcomes.

Table 3.4 Comparison of resolution and description of different DEM available for Zimbabwe

DEM	RESOLUTION (m)	DESCRIPTION
ASTER	90	Generated using stereo-pair images with a coverage spanning latitudes 83° north and 83° south and available in 30-meter postings and 1 x 1 degree tiles.
ETOPO2	3600	Generated from a digital database of land and sea-floor elevations on a 2-minute latitude/longitude grid
ETOPO5	9600	Generated from a digital database of land and sea-floor elevations on a 5-minute latitude/longitude grid.
Global DEM (GDEM)	30	Consists of a number of different DEM's created for the globe such as the ASTER
GTOPO30	30	Derived from several raster and vector sources of topographic information and has been divided into tiles for easier distribution
Shuttle Radar Topography Mission (SRTM)	90	Created from a specially modified radar system that flew on board the Space Shuttle Endeavour to generate a complete high-resolution digital topographic database of earth

3.2.3 Sampling and scale

One of the major challenges in using collar data in studies is creating a sampling plan, size, and procedure (Johnson & Ganskopp 2008). Sampling size is limited to the collared animals and is random as collar data is from only tagged animals within a study. Sampling plan and procedure are determined by the way the collar is set to collect and record readings (Cushman 2010), which is either frequent time gaps, or more infrequently. Frequent sampling is advantageous in that it maximises behavioural information whilst infrequent sampling may be necessary in describing long-term behavioural patterns (Meyburg & Meyburg 2009). In the study, the satellite collars had high frequency sampling of eight readings per day (a reading every six, four, one, one, five, five and

one, one hours). The study did not include the first five days after collaring to avoid spatial autocorrelation and biased sampling (Withey, Bloxton & Marzluff 2001; Elith & Graham 2009). However, this was not consistent as some packs changed the collared dog during the study period. Movebank is a new online repository (www.movebank.org) for species data that was explored in an effort to gain insight on wild dog data, but could not be used due to data agreements.

A models suitable scale is important in ecological studies (Stockwell & Peterson 2002; Elith & Leathwick 2009) because scale relates to the details identified from data and as such, the accuracy and applicability of the resulting model (Austin & Van Niel 2011). Whilst the ideal scale can be understood from literature, data availability plays a role in determining the scale at which the model can be run because fine scale data can be up-scaled to larger scales but the reverse is not possible (Madej 2001). The study aimed to model wild dog movement and distribution patterns and the chosen scale was supposed to explain these movements using different variables. Wild dog are a wide-ranging species (Lindsey et al. 2011; Jackson et al. 2014) and data needed for the study was available in different scales. Therefore, following Nonaka (2011) who modelled wolves that are also wide-ranging at a scale of 1 km by 1 km, the study modelled wild dog movement, and distribution at the same scale.

3.3 METHODS

The main aim of this study was to propose wild dog corridors in south-eastern Zimbabwe. To do this, firstly the study explored wild dogs denning behaviour, secondly, where wild dog were in geographical space by defining their UDs. Lastly, their probability distribution was mapped by analysing variables that influenced their seasonal movement and distribution patterns and using species distribution modelling (SDM) and applied outside GNP and SVC to propose conceptual wild dog corridors.

Qualitative methods are exploratory techniques (Taubman et al. 2013) used in studies where the researcher does not have possible hypotheses on the outcomes of the study (Longley et al. 2006). Quantitative methods are techniques that have conclusive results (Chang 2006) used in studies where samples can be used as representatives of a whole population (Allen 2010). However, Straub et al. (2013) points out that not all studies fall into one distinct group as some research uses both

qualitative and quantitative methods (Mitchell 1999; Mouton 2001). Use of both techniques is referred to as a correlative method (Tomlinson 2006) which Allen (2010) suggests is the best approach to use in most studies. This study used a correlative approach. Qualitative methods identified models and methods to use to answer the research questions. Quantitative approaches were adapted to justify the sample size and to measure the accuracy of the SDM in modelling wild dog distribution as well as wild dog corridors.

3.4 DENNING

Locations where wild dogs gave birth to pups and raised them before they join the pack are dens (Theuerkauf, Rouys & Jedrzejewski 2003). Start dates were identified as the earliest date in the cluster whilst end dates were the date the wild dogs left the den locations. In the study, dens could not be identified using female wild dogs stationary data because none of the packs had the alpha female collared. Only packs with a complete cold and dry season data in one year could have den locations and periods identified. A den was identified by creating 20 m buffers around each locality point from 15 April to 15 September of one year, and delineating clusters from the buffers because den sites identified using collar data are less than 20 m accurate (Bowman et al. 2000; Eriksen et al. 2009; Wierda 2010). The centre of the clusters with more than two GPS positions used consecutively for more than three days (Alfredéén 2006), pinpointed the location of the den. The study following Nonaka (2011) identified only one den site as the primary den even though wild dogs can change den locations. This was due to bias and inaccuracy of GPS data and because secondary dens are close to the first den as only the alpha female can move pups one at a time. The study also assessed how far the wild dogs moved from the dens during denning seasons by running the Euclidean distance tool on the den locations and overlaying the output with the wild dog locality points from the denning period to measure distances.

3.5 WILD DOG UTILIZATION DISTRIBUTION

Due to the pack structure of wild dog (Rasmussen 1997; Woodroffe et al. 2007) and the territorial behaviour of large carnivores (Goldman 2009), it is unlikely to find them present in each other's territories. However, due to limited resources in reserves, large carnivores may cross these boundaries at different times (Woodroffe & Ginsberg 1998). To get general idea of each pack's use

of geographical space in different years, yearly wild dog shapefiles were created for GNP and SVC in ArcGIS 10.1 using the select by attribute tool on each pack and years from 2009 to 2013 were assigned different symbology based on pack name to identify overlaps.

3.5.1 Geographic distribution

The general wild dog use of space was informative but did not outline the extent of wild dog UD and T-LoCoH was used to map wild dog UDs. T-LoCoH was chosen for the study because it used time stamps on the locality points to create and explore wild dog UDs for each pack using different isopleths levels (Lyons, Turner & Getz 2013). In the isopleths, 0.1-level meant highest occurrence of locality points and 0.95-level meant lowest occurrence of locality points. 0.95-level isopleths mean 0.05 of the wild dog locality points are not included in any of the isopleths. T-LoCoH was run as a script in R for each of the packs per season (Appendix A).

3.5.2 Temporal distributions

IVG is a unit of time that must pass before another occurrence in a hull is considered a separate visit. Both re-visitation rate and duration of stay were calculated using an Inter-Visit Gap (IVG) of 24 hours to get a good reflection of wild dog daily cycles in movement. T-LoCoH was used to assess whether the relationship between wild dog UDs levels, re-visitation rates, and durations of stay had general patterns. This was done in ArcGIS by intersecting T-LoCoH's output of each packs' points with re-visitation rate and duration of stay values with isopleth levels. Secondly, the points were colour coded by isopleth value and plotted with the re-visitation rate on the y-axis and duration of stay on the x-axis.

3.6 WILD DOG PROBABILITY DISTRIBUTION

Wild dog probability distribution is based on current locations, denning seasons, locations, and UDs. As shown above, each of these methods contributed to explaining wild dog distribution in

preparation of mapping their probability distribution outside GNP and SVC. In addition, SDM require biotic and abiotic correlates to species movements and distributions (Austin 2007).

3.6.1 Variables influencing movement and distribution

Biotic and abiotic factors determine the regions accessible to a species and its ability to adapt to its environment (Chefaoui 2011). The major threat to wild dog is the loss of their habitat (Kratt & Kratt 2013). Predictors influence the response expected between species and biotic and abiotic variables (Austin 2002). Table 3.5 presents the biotic and abiotic variables that can be used to assess causes of habitat fragmentation and loss. Anthropogenic activities are the result of human-wildlife conflict in both GNP and SVC and are the cause of habitat loss in numerous reserves (Graf et al. 2006). Road kill is responsible for high mortality rates in the reserves as well as reduction of wildlife's habitat in order to develop better road networks (Woodroffe et al. 2007; Davies-Mostert et al. 2012). Boundary of reserves contributes to habitat loss if wild dogs are not able to cross these boundaries and access additional suitable habitat (Frantzen, Ferguson & de Villiers 2001). Elevation contributes to habitat intactness as wild dogs require higher elevations for den locations (Jackson et al. 2014) whilst water bodies contribute to habitat intactness as they influence the wild dogs prey (Woodroffe & Ginsberg 1998) and are required by lactating females (Burrows 2011). Vegetation density is important in habitats as it influences wild dogs' hunting and pup survival (Woodroffe et al. 2007). Rainfall contributes to pup-survival (Buettner et al. 2007) and temperature is important for prey availability as it influences prey thermoregulation (Wisz et al. 2008a).

The variables presented in Table 3.5 may alter between seasons causing seasonal movement and distribution patterns. In the study, seasonal wild dog shape files were created by separating the locality points based on their collection dates into the cold and dry (April to October) and hot and wet seasons (November to March). However, Nyarushanga pack in SVC had all its locality points in the cold and dry season and so had no "seasonal" movement. Prior to analysing the influence of the biotic and abiotic variables on the wild dogs' movement, the study assessed the variables correlation. All three biotic variables were assessed, but only four of the abiotic variables were assessed excluding the vegetation data because it was categorical data.

Table 3.5 Biotic and abiotic variables derived from the seasonal distributions used in wild dog distribution model to determine other areas that wild dog can survive outside GNP and SVC

Variable	Source	Measurement		Motivation
		Raster	Vector	
Distance to human settlements	Landsat 8 imagery	30 x 30 m		Plays a role in habitat loss for wild dog as it leads to the partitioning of the landscape (Graf et al. 2006). This affects what wild dog considers a safe distance from the human settlements and their activities.
Distance to roads	Tracks for Africa (Zimbabwe Roads)		1:500 000	Road kill and development of road networks also partitions the landscape resulting in habitat loss for wild dog (Woodroffe et al. 2007) as well as increased mortality rate of large carnivores (Davies-Mostert et al. 2012) .
Distance to boundaries of reserves	Peace Parks Foundation (Zimbabwe reserves)		1:500 000	Failure or restriction of wild dog to move outside boundaries of reserves contributes to habitat loss (Frantzen, Ferguson & de Villiers 2001) as wild dog fail to access additional suitable habitat beyond GNP and SVC's borders. As it is, wild dog in GNP and SVC have limited movement outside the reserves (Groom 2013b, Pers com).
Elevation range	SRTM	90 m x 90 m		Whilst elevation is not a major determinant of wild dog movement (Rasmussen & Macdonald 2011), it does have bearing on wild dog den locations (Jackson et al. 2014) such that additional habitat will be influenced by the terrain in those areas.
Distance to rivers	FAO Africa Water Data (Africa Rivers)		1:1000	Wild dog prey movement and availability is dependent on rivers (Woodroffe & Ginsberg 1998) such that absence of sufficient rivers reduces the habitat intactness in an area for wild dog. In addition, lactating females require large amounts of water nearby.
Vegetation type	Zimbabwe Vegetation		1: 500 000	Woodroffe et al. (2007) emphasized the role that vegetation density has on wild dog activities such as hunting. Therefore, vegetation density may limit wild dog from moving into additional areas and maybe a challenge in additional areas with habitat.
Rainfall range	WorldClim data	1 km x 1 km		Rainfall contributes to pup survival rates in wild dog ecology (Buettner et al. 2007) as it determines how long pups are likely to survive after birth. Therefore, rainfall totals in additional area is a factor contributing to habitat loss.
Temperature range	WorldClim data	1 km x 1 km		Wild dog are not directly affected by temperature, but their prey requires suitable temperatures for thermoregulation and other ecological characteristics (Wisiz et al. 2008a). Therefore, temperature contributes to habitat loss if prey is unable to withstand temperatures or gain in areas where prey has adapted to the temperature there.

3.6.1.1 Biotic variables

Human influences were considered to have a biotic variable because of their interaction with wild dog. Wild dogs are considered vermin and predators of livestock by humans (Frantzen, Ferguson & de Villiers 2001). In addition, human influences affect wild dogs' seasonal movement because whilst infrastructure does not change seasonally, human activities in the study areas do change according to season and thus affect wild dogs' prey. Therefore, human influences in GNP and SVC were buffered with distances of 5, 10 and 20 km (Figure 3.3) and overlaid with the seasonal wild dog shapefiles. The study assessed the effect distance to the human influences had on seasonal movement for different packs as well as between males and females.

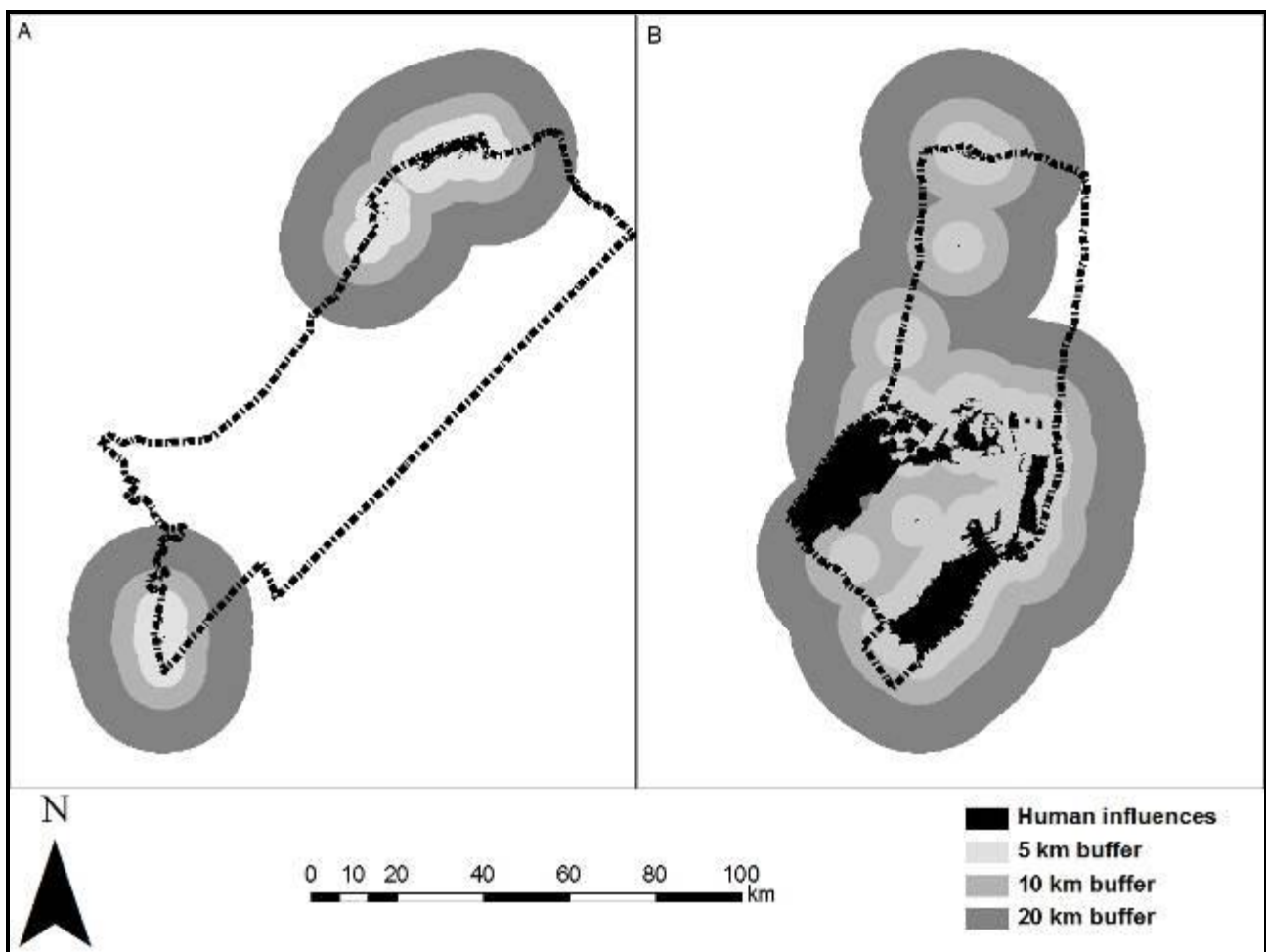


Figure 3.3 Human settlements in GNP (A) and SVC (B) with buffers of 5 to 20 km.

Road networks may determine seasonal wild dog movement and distribution patterns in an area (Andrew, Wulder & Coops 2011). This is because their presence in reserves leads to variation in

traffic weights in different seasons and at different times. The roads were buffered by 5, 10 and 20 km in GNP and SVC (Figure 3.4) and overlaid with wild dog seasonal shapefiles to investigate whether there were changes in movement and distribution patterns around the roads for different packs as well as between males and females.

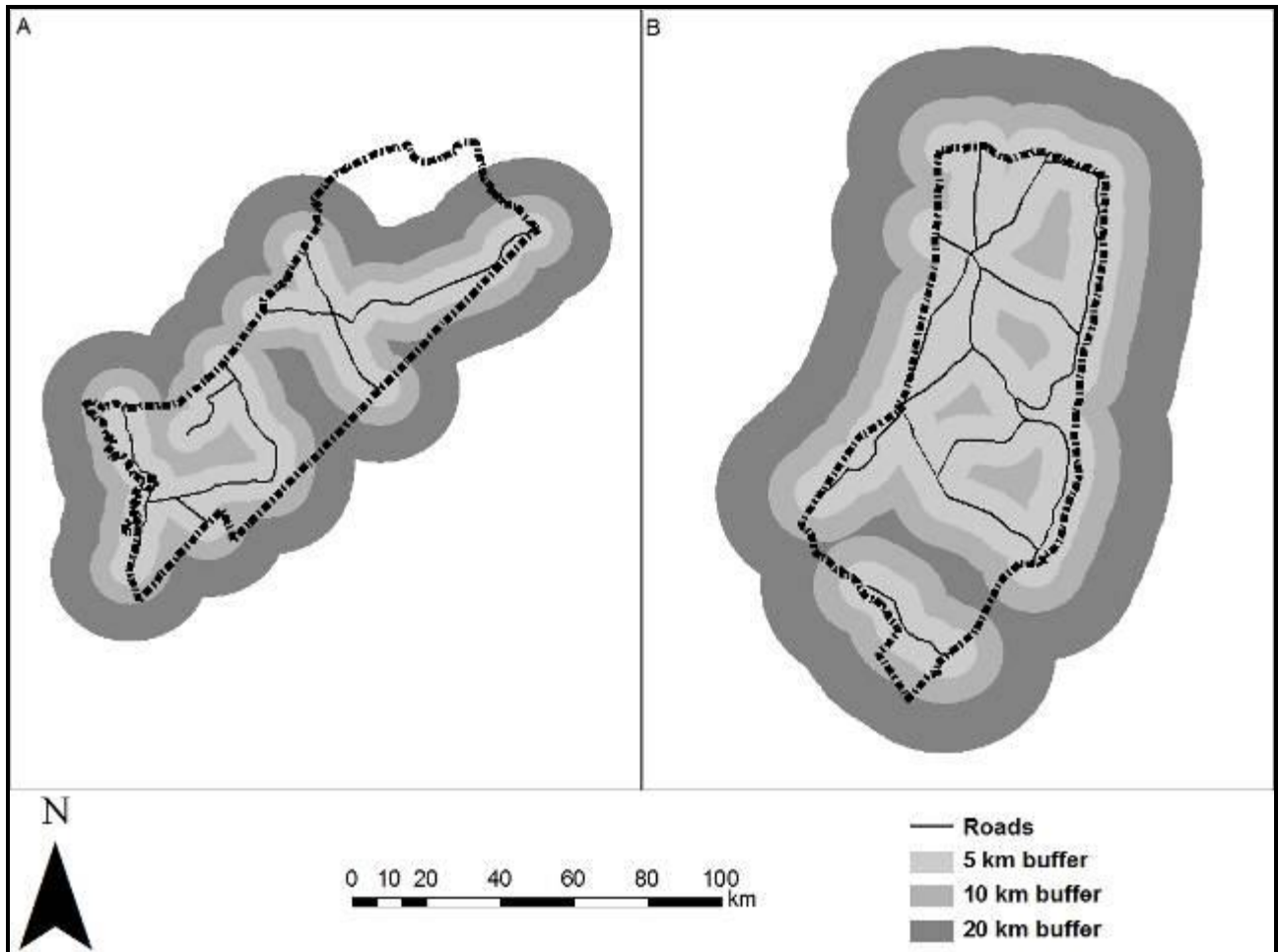


Figure 3.4 Roads in GNP (A) and SVC (B) with buffers of 5 to 20 km.

The study also assessed whether the boundary of the reserves was a biotic variable that influenced wild dog seasonal movement and distribution pattern. Generally, boundaries do not affect large carnivores, as they are able to continue processes such as hunting within the boundary (Hayward et al. 2007; Büscher & Schoon 2009; Packer et al. 2009). Large carnivores mostly prefer to keep inside the boundaries because persecution increases outside reserves boundaries (Frantzen, Ferguson & de Villiers 2001). In GNP and SVC, wild dog have limited movement outside the boundaries (Groom 2013a, Pers com) although it is unclear if the movement is season based, how far they move out and why there is limited movement. Therefore, the reserves were buffered from

their boundaries with distances of 5, 10 and 20 km (Figure 3.5) and overlaid with the seasonal wild dog shapefiles to record movements and distribution patterns outside of GNP and SVC's boundaries based on different packs and sex.

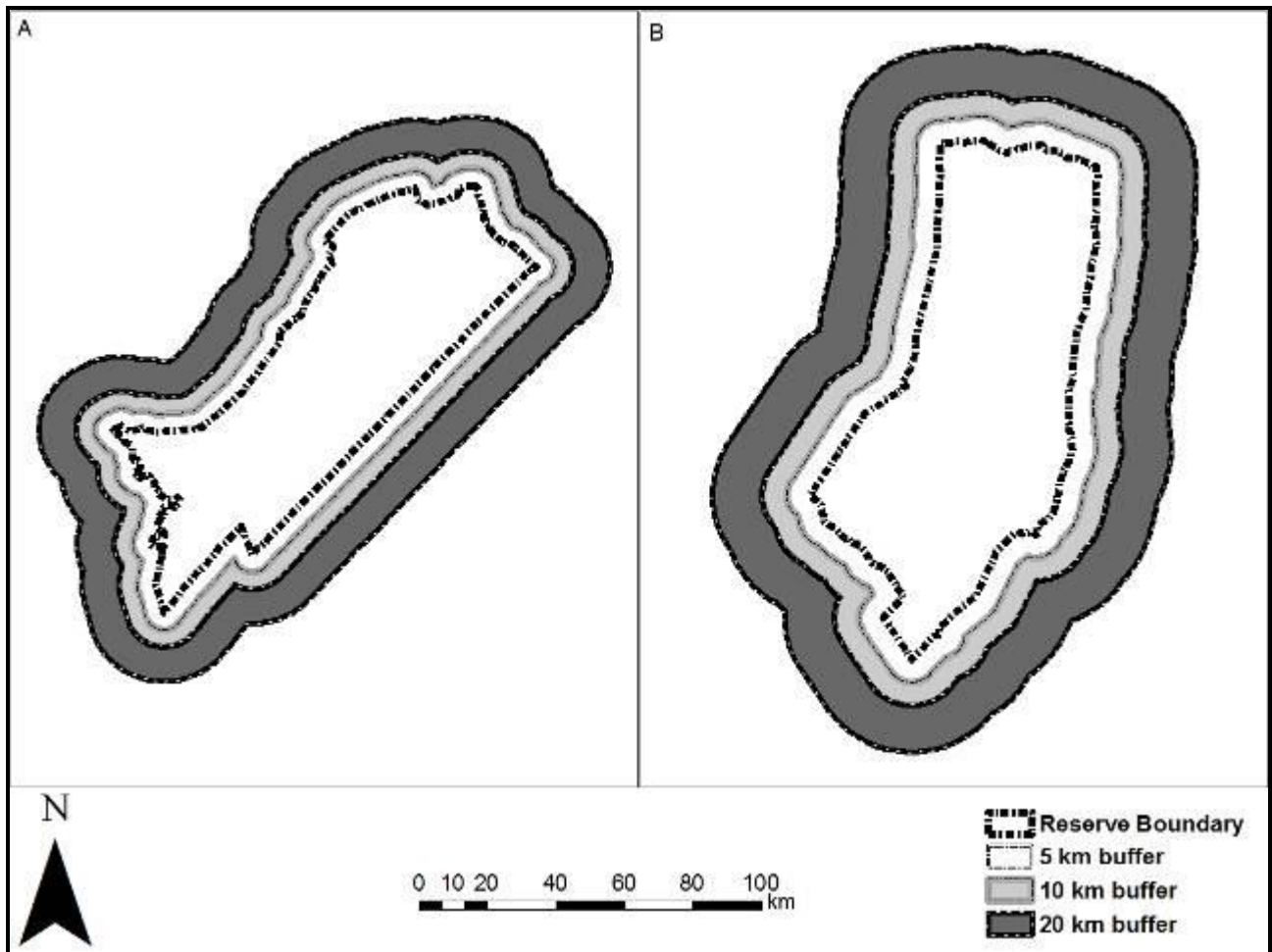


Figure 3.5 Buffers of 5 to 20 km from the boundaries of GNP (A) and SVC (B).

3.6.1.2 Abiotic variables

Due to the wide-ranging nature of wild dog, previous literature suggested that elevation does not largely affect their movement and distribution (Rasmussen & Macdonald 2011). However, recent literature suggested that aspects of their ecology such as denning and pup guarding might be dependent on the elevation of their habitat (Davies-Mostert et al. 2012; Marsden et al. 2011). As such, even though both GNP and SVC are relatively flat areas the study assessed the influence elevation had on seasonal movements and if this influence was similar for different packs and

between males and females. This was done by overlaying wild dog seasonal shapefiles with the SRTM to identify elevation ranges that wild dog moved in GNP and SVC during the different seasons.

Water availability depends on the precipitation available in the study area and while wild dog get their water from preys' blood (Lindsey et al. 2011), wild dog occasionally need large amounts of water nearby for lactating females (Burrows 2011; Davies-Mostert et al. 2012). Wild dogs' prey drink s water (Hunter et al. 2014) and the prey's movement around rivers presumably influences wild dog movement during hunting times usually at dawn and dusk (Woodroffe & Ginsberg 1998; Kratt & Kratt 2013). Therefore, the rivers in GNP and SVC were buffered by distances of 1.25, 2.5, 5 km (Figure 3.6) and overlaid them with the seasonal wild dog shapefiles to investigate the relationship between wild dog and proximity to rivers for different packs as well as sexes.

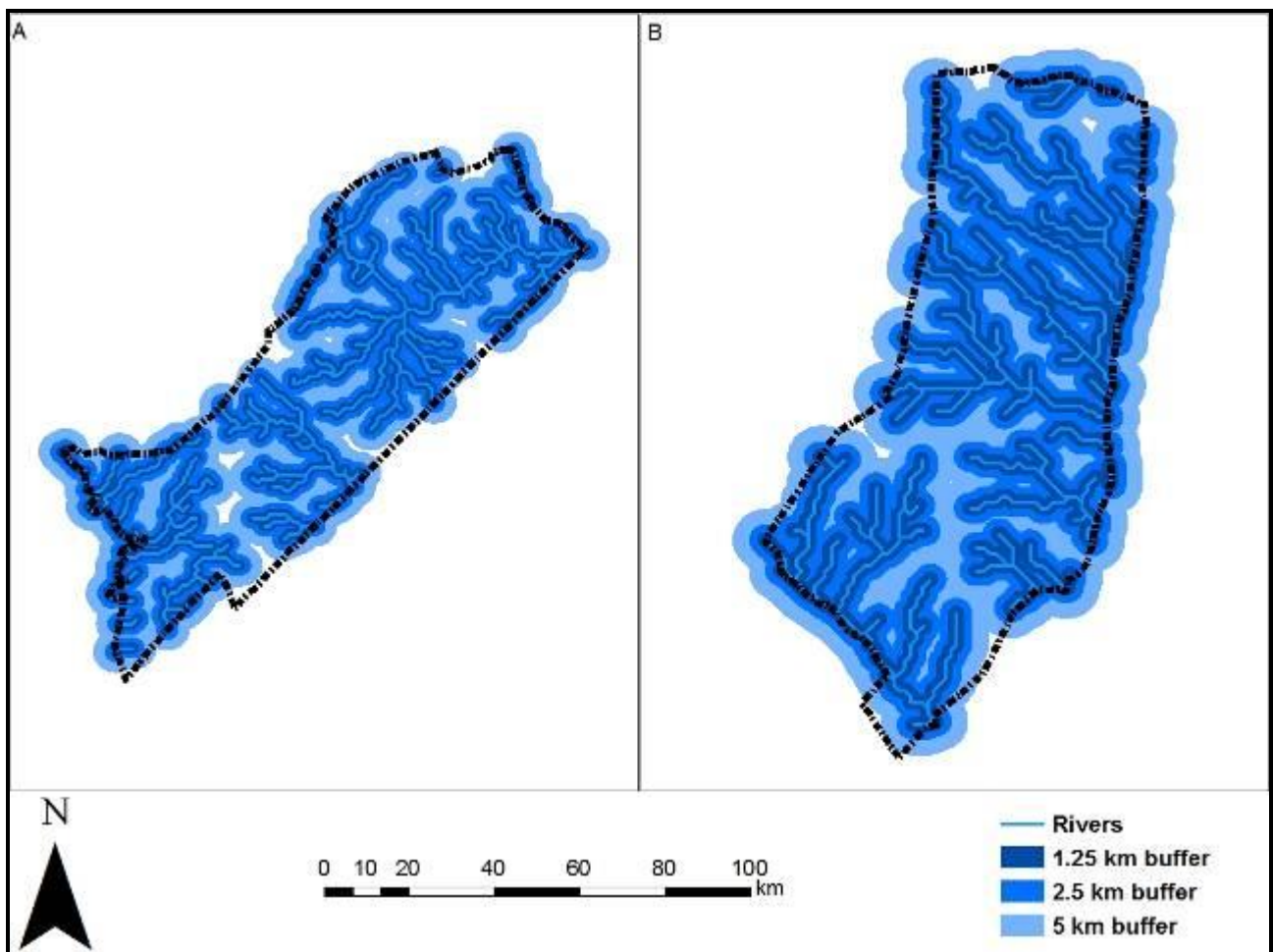


Figure 3.6 Rivers in GNP (A) and SVC (B) with buffers of 1.25 to 5 km

Vegetation cover has no direct impact on wild dog movement (Woodroffe & Sillero-Zubiri 2012) but its density does vary with seasons (Pittiglio et al. 2012). For example, more dense vegetation is present in wet periods and less dense vegetation in the dry periods, which affects wild dog hunting strategies. The study used vegetation cover as a surrogate for vegetation density overlaid with wild dog seasonal shapefiles for both GNP and SVC to assess whether vegetation influenced wild dog seasonal movement and distribution patterns for packs and different sexes.

Wild dog pups are more likely to survive after periods of low rainfall due to ease of hunting in dry seasons (Buettner et al. 2007) which suggests wild dog will favour areas with low rainfall. Worldclim temperature and rainfall data was available as monthly and annual layers whereas the study required seasonal layers. Therefore, using ArcGIS 10.1 raster calculator, monthly layers from April to October were averaged for the cold and dry season, and those from November to March for the hot and wet season. The rainfall seasonal layers were overlaid with wild dog seasonal shapefiles in GNP and SVC to assess rainfall ranges in the areas where wild dog moved in during the two seasons.

Wild dog thermoregulation allows them to survive in high temperatures and eat prey immediately after chase such that temperature is not a major influence in their movement and distribution pattern (Burrows 2011). Nonetheless, temperature presumably plays a role in wild dog denning seasons. Therefore, using the process described above for rainfall, temperature seasonal layers were created using Worldclim data. Temperature seasonal layers were overlaid with wild dog seasonal shapefiles in GNP and SVC to assess temperature ranges in the areas where wild dog moved in during the two seasons.

3.6.1.3 Investigation of relationship between variables

The data was logged in order to adjust the data's skewness and kurtosis values (Field 2007). Autocorrelation between the biotic and abiotic variables processed above was assessed using SPSS 21 to explore relationships between the variables, as spatially autocorrelated variables would cause inconsistencies in the study results. Pearson's two tailed correlation method was used as it provides higher accuracies for spatial data (Field 2007). Vegetation was excluded from the autocorrelation because it was the only categorical data included in the study.

3.6.2 Accessible areas to wild dog: model selection

Species fundamental niches depend on the areas accessible to the species (Soberón & Peterson 2005; Kearney & Porter 2009) and other areas the species can survive in (Lin 2008; Jantke & Scheinder 2010). Identifying areas wild dog could survive with sufficient habitat was done by firstly running BIOMOD on wild dog data within the parks using a script in R (Appendix B) with GLM, GAM, and MaxEnt (Guisan & Thuiller 2005). Test data was 25% of the presence data, training data was 75%, and prevalence was set to 0.5 to reduce the variability of the model per run and reduce RMSE errors (Phillips & Elith 2013). Thereafter, MaxEnt created by Phillips, Anderson & Schapire (2006) was used for the study because there were no confirmed wild dog absences (Phillips & Dudík 2008).

Wild dog locality points were prepared for the study by creating .csv files that contained each pack's name, longitude, and latitude. Biotic and abiotic layers discussed in Table 3.5 above were converted to raster layers with a cell size of 1 km² in ArcGIS 10.1. Distance rasters were created using the Euclidean Distance tool. Elevation was resampled using nearest neighbour to 1 km by 1 km cell size and vegetation was converted to a raster with the same cell size. Thereafter, all layers were converted to ASCII using the Raster to ASCII tool. Layers were prepared to suit MaxEnt's requirement that all input layers should have the same geographic bounds, cell size and be in the same projection (Phillips, Anderson & Schapire 2006; Young, Carter & Evangelista 2011). Fifteen replicates were used in each run whilst 25% of wild dog data was used as training data and the remaining 75% was test data. Training data was selected using a manual method that uses locality points, while study area geography and extent was used to select background samples (Phillips, Anderson & Schapire 2006; Young, Carter & Evangelista 2011). This was because specific background locations were selected from wild dog data in developing the model (Phillips & Dudík 2008; Elith et al. 2011). Replicates and test data ensured all input layers were included in the model's measure and variability. Finally, different regularization multipliers (smoothing parameters) were tested for the study (Figure 3.7) to ensure the model was neither too localised (over-fitted) nor generalized (under-fitted) (Phillips & Schapire 2006; Warren & Seifert 2011; Young, Carter & Evangelista 2011). The larger the regularisation multiplier value, the more smoothing required (Phillips & Dudík 2008). Therefore, a regularization parameter value of four was the appropriate calibration for the study to produce the most suitable results.

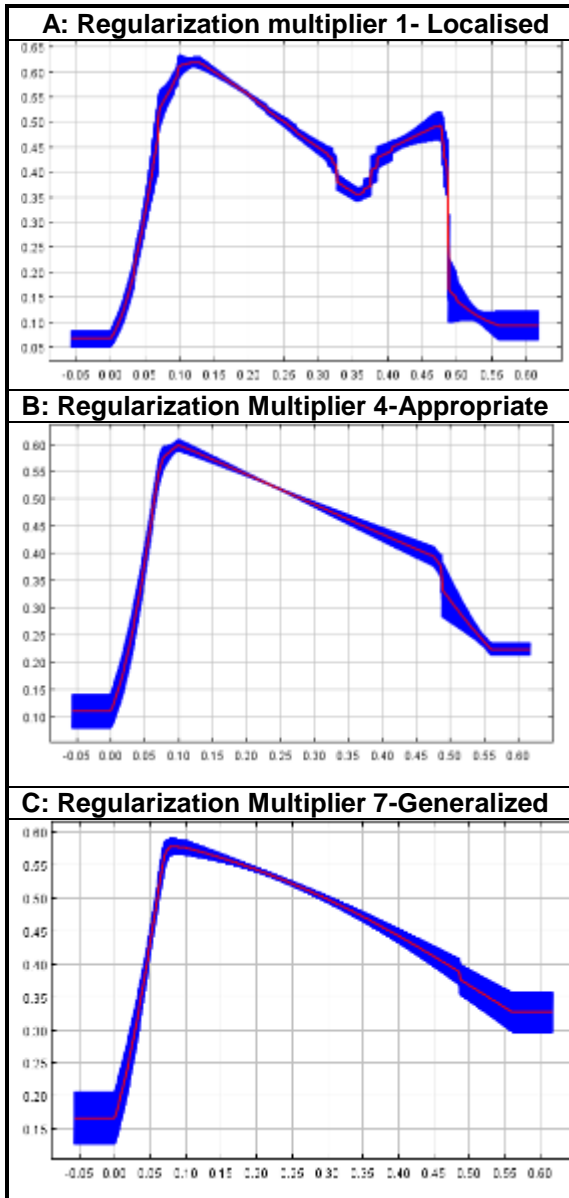


Figure 3.7 Effect of the value of MaxEnt's regularization multiplier with values 1 (A), 4 (B) and 7 (C) on the response curves showing the influence of distance to human settlements in GNP on the MaxEnt prediction. It plots logistic prediction on the y-axis against its weight in the model on the x-axis

MaxEnt produces maps that show where a species is persisting in a given study area (Johnson 2007; Phillips & Elith 2013). These maps are known as probability of occurrence maps (Elith et al. 2011) because they identify where a species is in an area and applies the biotic and abiotic variables limits to other areas to decide if the species can survive in them (Young, Carter & Evangelista 2011). The average distribution model was averaged with the "10 percentile training presence logistic threshold" value in the .csv file using Raster Calculator to account for possible errors and bias in the data. Model results were compared to BIOMOD's results in order to ensure there was cross validity and confirmation of the variables influencing movements of wild dog inside and outside the parks.

3.7 EXPERIMENTAL DESIGN

The methodology used in the study was based on the ecological niche theory. The study presents the methodological framework shown in Figure 3.8 as the methods to be followed in order to suit the theory's requirements for species studies to analyse wild dog movement and distribution patterns from collar data.

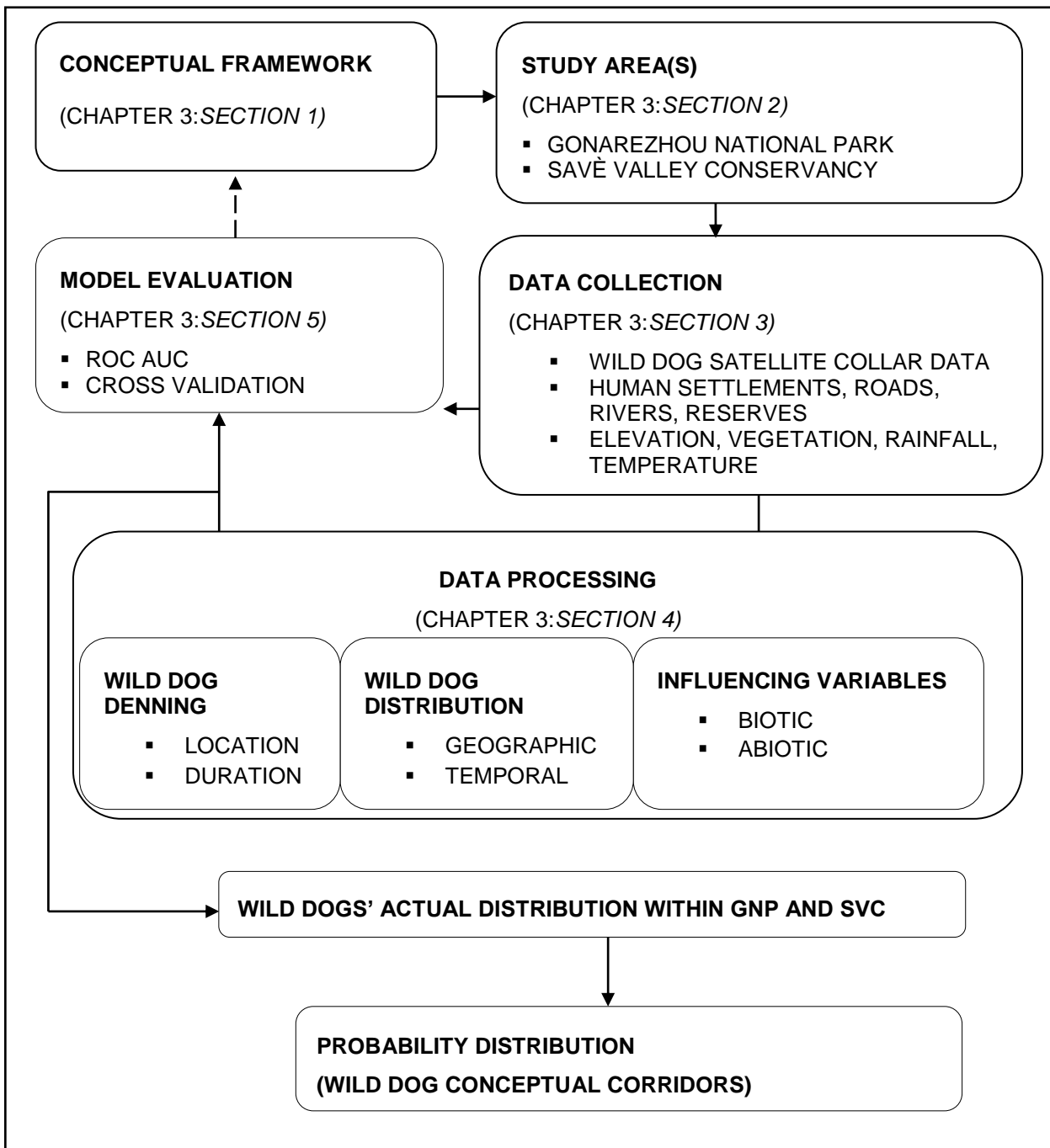


Figure 3.8 Experimental design giving systematic detail of the methods used in the study in their chronological order

CHAPTER 4: WILD DOG DENNING

Denning is an important ecological process for wild dog because its success influences survival of wild dog populations (Woodroffe et al. 2005) and wild dog movement and distribution patterns (Romañach & Lindsey 2007). A denning season is successful if a large number of pups survive and join the pack to make it to adulthood and reproduce (Kratt & Kratt 2013). Denning is the period where pups are born by the alpha female and due to social pack dynamics taken care of by the pack as a whole (Burrows 2011). Other adults and yearlings hunt to provision the pups or guard them from predators (Hunter et al. 2014). Although their denning sites differed for the same pack in different denning seasons and from pack to pack, a common characteristic for all den sites was their locations in higher altitudes in the reserves. Wild dog in both GNP and SVC denned consistently during the cold and dry season although when they started and ended differed in each denning season. Chapter four identifies wild dog den locations and measures the duration of the denning season for wild dog packs.

4.1 DENNING SITES

None of GNP's packs could have den locations or durations of denning identified because none of them had wild dog locality points for a complete cold and dry season in one year. In SVC, the study identified den locations for five packs and the collared male dog, Tick, for different years (Figure 4.1). Only the Batanai pack could have den locations from different years assessed (2011 and 2012) and these dens were close to one another. A common characteristic in the dens is that they are always more than 10 km from human settlements; can be less than 10 km from the roads; are always in close proximity to rivers (furthest den site was 10 km from a river) and do not in any instance occur outside SVC's boundary. In addition, the den locations also occur in the areas with the higher elevation in SVC where they seem to be following a ridge; are characterised with Terminalia/Combretum vegetation and are in areas with high temperatures receiving low rainfall.

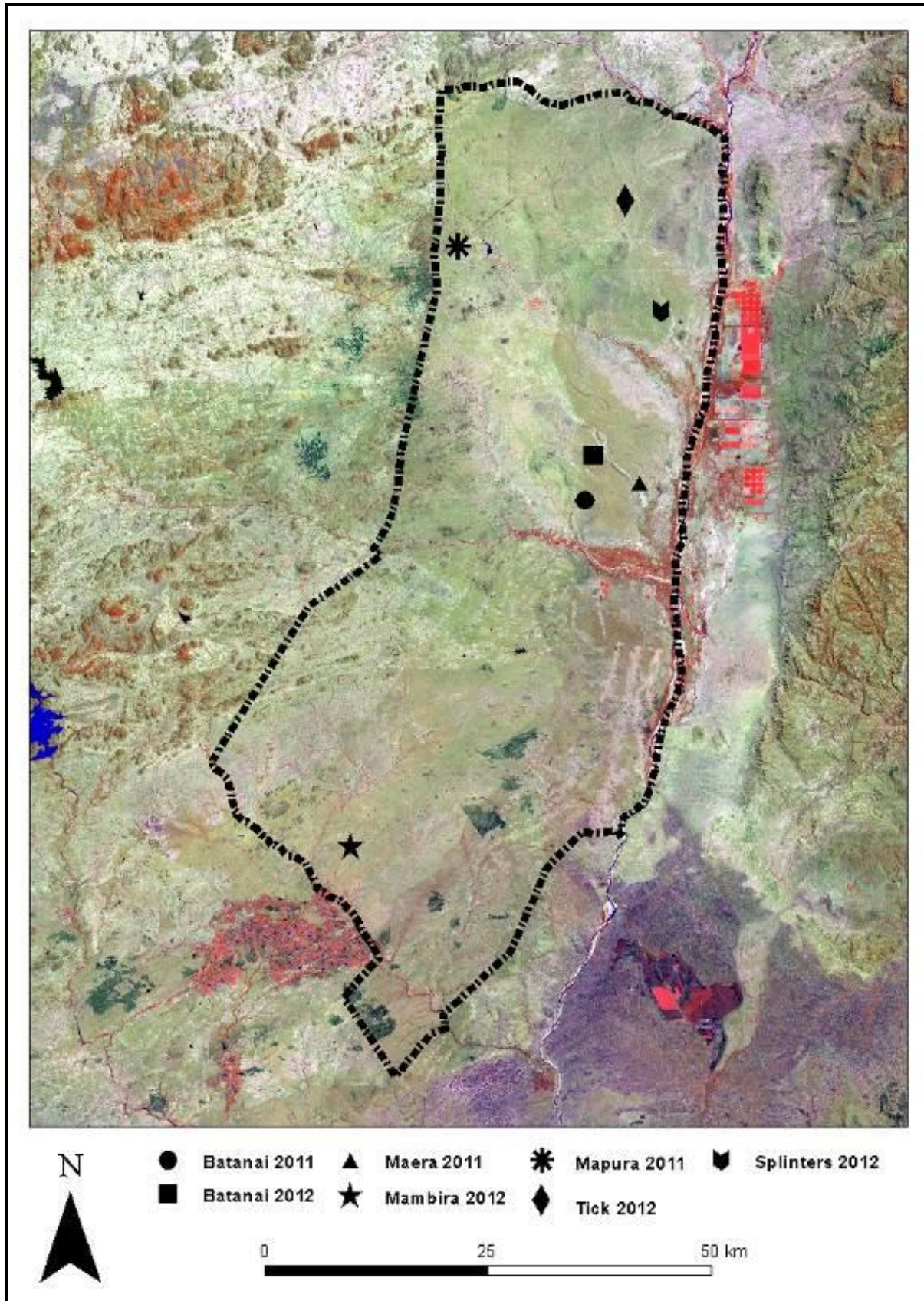


Figure 4.1 Den locations for five of the collared packs in SVC from 2011 to 2012. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

Den locations were assessed to show similarities and differences. The study confirmed that wild dog did not consistently use the same den although a den site could be re-used as suggested by Lindsey et al. (2011). However, this conclusion is biased in the study as it is based on the results of one pack. Secondly, SVC wild dog dens were in areas that were close to water bodies, and far from human settlements and roads. Whilst protection from predators could not be assessed in the study, it can be inferred that they avoided areas with high predator densities, as they preferred complex elevations for their den locations. These characteristics confirm that the main drivers behind den locations include distance to water for lactating females (Davies-Mostert et al. 2012), sufficient protection from predators (Lindsey et al. 2011) and higher elevations (Jackson et al. 2014). These factors also affect wild dog prey such as impala, which would not be found in areas with high elevations which adds to the findings of Woodroffe (2010) and Vanak et al. (2013) that dens are not found in areas where there is high prey density. Each of these factors also confirms that overall, a den site is chosen primarily to increase pups chances of survival (Buettner et al. 2007; Graf et al. 2006).

4.2 DENNING DURATION

The denning start and end dates for the packs in SVC differed per pack and for the same pack in different years (Table 4.1).

Table 4.1 Denning start and end dates per year for five wild dog collared packs in SVC from 2011 to 2012

Pack/ Individual Dog Name	Years	Denning start date	Denning end date
Batanai	2011	21 April	27 July
Batanai	2012	14 May	15 August
Maera	2011	17 May	05 July
Mambira	2012	19 April	06 July
Mapura	2011	12 July	24 September
Splinters	2012	31 May	17 August
Tick	2012	11 April	21 June

On average, denning was from April to September (Figure 4.2) lasting a minimum of 10 weeks and a maximum of 13 weeks. However, there was no consistency for when in the year the packs den. Batanai's denning period in the two separate years showed variation from April - July in 2011 to May - August in 2012.

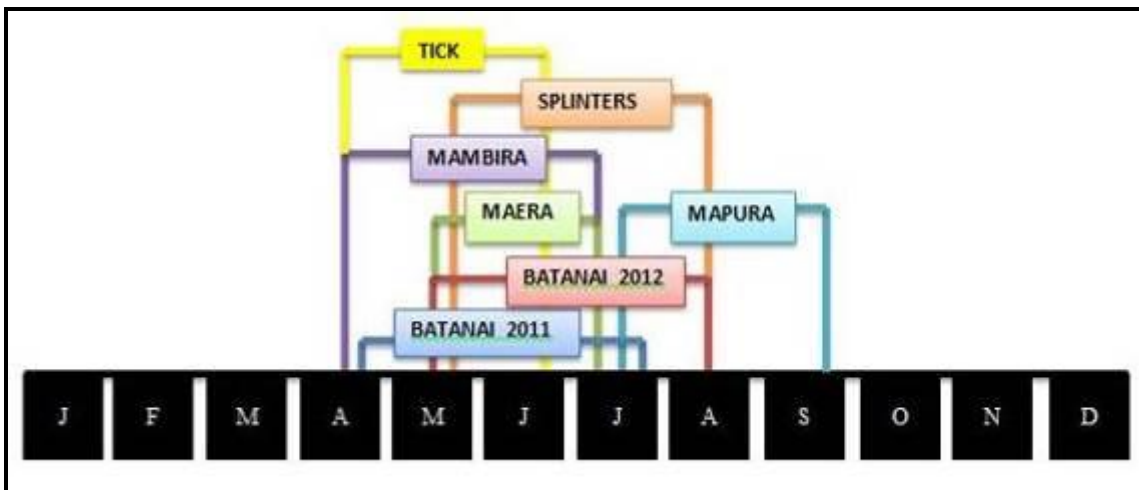


Figure 4.2 Denning timeline for five wild dog collared packs in SVC from 2011 to 2012

Denning durations were assessed to understand wild dog denning seasons. The results confirmed Burrows (2011) suggestion that wild dog may alter denning seasons in different years as shown by the variation in beginning and end dates for Batanai in 2011 and 2012. This is also a biased conclusion as it is based on only one pack. In addition, the study also confirmed that denning occurs once a year and lasts for a total of 10 to 12 weeks (approximately three months) (Romañach & Lindsey 2007; Burrows 2011).

Duration of the denning season varies with location and there is no minimum or maximum time wild dog can spend at one den location because hyenas may or may not discover the den and bacteria does not have a period in which it will attack a den (Burrows 2011, Kratt & Kratt 2013). Whilst in GNP and SVC denning was in the cold and dry season from April to September, other studies have found wild dog to den in different seasons such as the hot and wet season in other areas (Burrows 2011; Groom 2014, Pers com). Therefore, the study could not explain why these seasons differed but suggests this may be linked to wild dog aiming to den in seasons with conditions that will likely increase chances of pup survival as suggested by Graf et al. (2006).

4.3 DENNING INFLUENCE ON MOVEMENT PATTERNS

Wild dog locality points during the denning season in SVC expressed as percentages to represent the distance from the den sites wild dog maintained (Figure 4.3). In 2012, alone whilst just above a

third of Batanai's movement was within 5 km from the den, about two thirds of Mambira's movement was within 10 km, and Splinters had more than two thirds within 5 km whilst Tick had less than one third within 5 km. The distance moved from the den location also differed for the same pack in different years. In 2011, close to two thirds of Batanai's movement was within 5 km of the den whereas in 2012 this movement changed to just above a third of the total movement. From 20 km away to more than 20 km away from the den, the movement is minimal and packs such as Splinters have no movement at all that far from their dens.

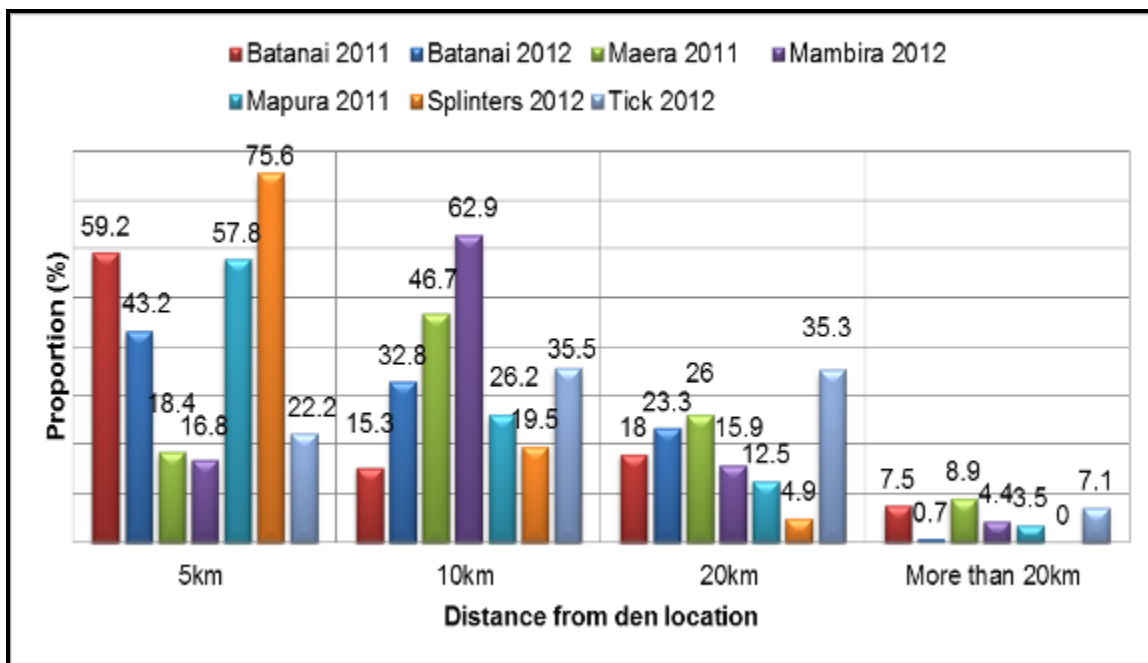


Figure 4.3 Wild dog locality points during the denning season in SVC expressed as percentages to represent the distance from the den sites wild dog maintained

The distance wild dog maintained from their den sites was assessed to see how the dens affected wild dog movement and distribution patterns. The results showed that the den locations did alter the movement and distribution from being generally dispersed (Woodroffe et al. 2005; Hunter et al. 2014) to being clustered. Movement was limited to mostly less than 10 km around a den whereas they travel over 300 km in a day (Cloutier & Packard 2014). This confirmed Jackson et al. (2014)'s study results that showed that den locations do alter wild dog movement and distribution pattern as the pattern changes from generally dispersed to clustering during denning seasons. In addition, whilst literature suggested that wild dog did not move "far" from their den sites (Jachowski et al. 2010) the study showed that in SVC they rarely move more than 20 km away. However, this conclusion was from six observations in one reserve such that it requires further investigation.

CHAPTER 5: WILD DOG ACTUAL USE OF SPACE

In order to fully understand wild dog movement and distribution patterns, their utilization distributions (UDs) should be studied and understood (Romañach & Lindsey 2007; Hunter et al. 2014). UD outlines the probability distribution of wild dog in an area based on their use of space over time (Getz et al. 2007) and in this study are used to identify wild dogs' home-range. The UD assists the ecological niche theory by identifying the areas that are accessible to the species (Soberón & Peterson 2005). Four packs were collared in GNP's 5 053 km² from 2010 to 2013 and nine packs and two individual dogs were collared in SVC's 3 450 km² from 2009 to 2013. This means an average of one dog was collared per year in GNP and an average of two dogs per year in SVC. A home-range is the geographical space an animal uses as habitat and for movement (Bauer 2003; Cumming & Corneils 2012) whereas a UD is the geographical distribution an animal is assumed to use based on GPS data collected from the animal over time (Pearce & Boyce 2006; Cumming & Corneils 2012). In this study, the UD was used to make an approximate measure of the wild dogs' home-range. Wild dog packs' use of geographical space differed between seasons with resulting UD having an average size of 236.41 km² during the cold and dry season than an average of 331.34 km² during the hot and wet season although size and extent differed per pack and per isopleth level. In addition, frequency of wild dog visits to areas in their UD and duration of stay in these areas varied for different areas and with isopleth levels. Chapter five presents wild dog UD, re-visitation rates and durations of stay in their UD for different packs and different sexes.

5.1 CHARACTERISTICS OF WILD DOG USE OF SPACE

From 2010 to 2011, only one pack was collared in GNP (Figure 5.1a) namely Mabalauta such that its use of space could not be compared to other packs. In 2010, the movement was restricted to southern GNP, but in 2011 although majority of the movement was still concentrated in southern GNP; there was additional movement in central and north-eastern GNP, and outside the reserve boundary (Figure 5.1b). From 2012 to 2013, three packs were collared and they did not use the same geographical space as none of their locality points overlapped in both years. Although both Mabalauta and Shangana used the same space in southern GNP, these wild dogs were not collared in the same year and Mabalauta extended more to central and northern GNP than Shangana who stayed in the south. Mabalauta's movement in 2010 was slightly widespread and her movement

outside the park's boundary was mostly in the southeast. Shangana's use in 2012 was concentrated and his movement outside the park boundary was mostly to the south-west.

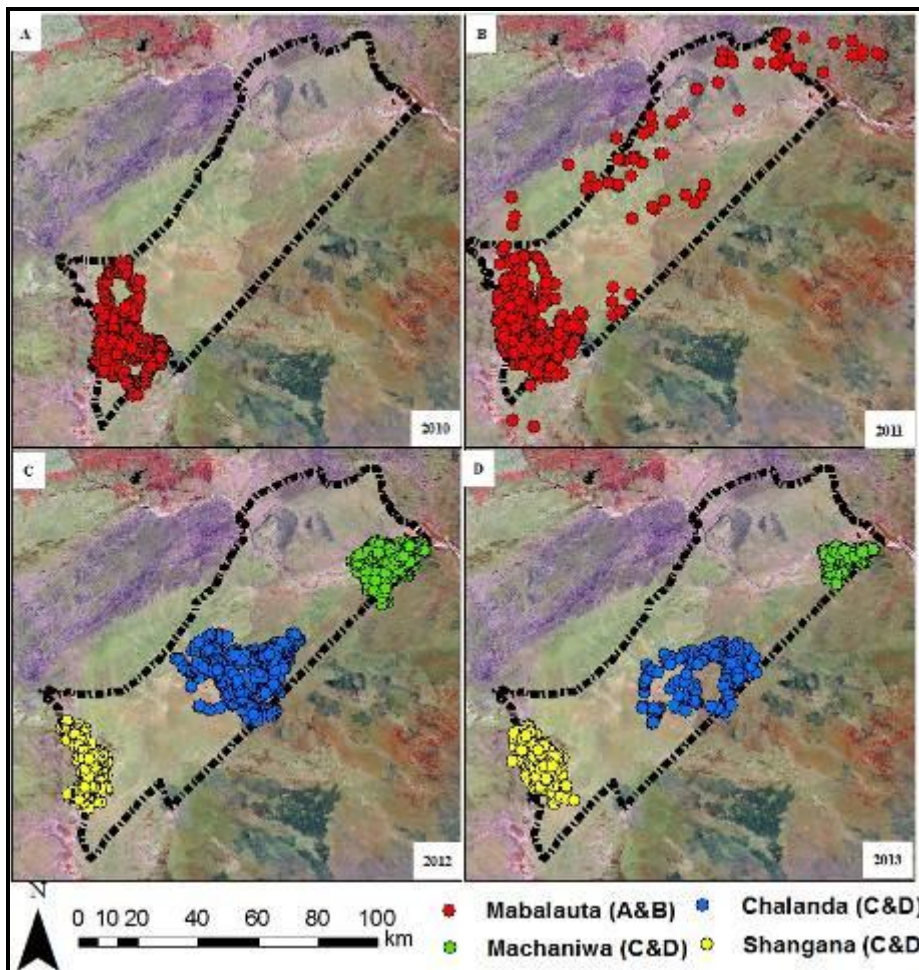


Figure 5.1 Distribution of the four collared wild dog packs in GNP used in the study from 2010 to 2013 (A to D). Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

In SVC (Figure 5.2), packs collared in the same year used the same geographical space albeit only at the edges of where the packs' movement was concentrated. Whilst Star seemed to maintain territoriality in 2009, Bedford and Maera did not maintain territoriality through to 2010 where Bedford began crossing Mapura's territory as well as move outside the reserve boundary. In 2011 Batanai, Bedford, Maera, Mapura, Patch, and Tick crossed one another's territories and Mapura, Patch and Mambira also moved outside the reserve boundary. In 2012, Crocodile and Splinters were collared and their movement not only crossed the other's territories, but was also not far from the other packs. In 2013, a sense of territoriality existed where Batanai, Crocodile, Mambira, Splinters, and Tick were close, but did not cross one another's territories. In the north west of the conservancy

Batanai, Maera, and Patch used the area interchangeably from 2010 through to 2012. Bedford's movement in 2010 was more clustered as compared to Batanai's movement in 2011 and the areas with density of points differed for these packs. Where, Batanai's clusters were to the north-west and south-east of Bedford's clusters. Patch and Ticks' movement overlaid almost completely which may suggest they are from the same pack. Batanai and Splinters movement suggest "zones of agreed use" where different packs can use the same areas together on the edges of where their locality points cluster, but maintain territoriality in the core areas of use.

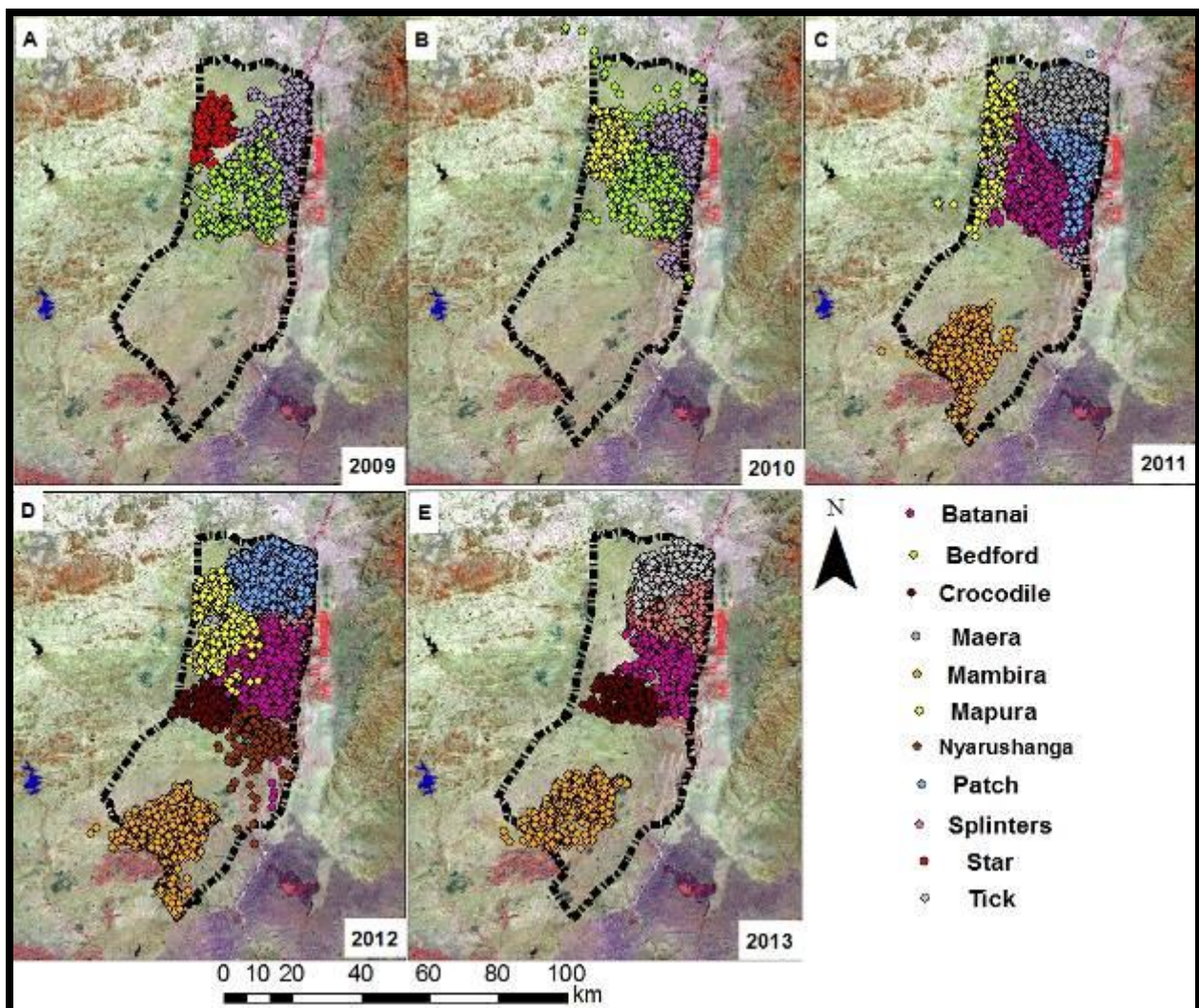


Figure 5.2 Distribution of the nine collared packs and two individual wild dog in SVC used in the study from 2009 to 2013 (A to E). Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

Yearly use of space by wild dog was assessed to get a general idea of how wild dog packs used geographical space in relation to other packs. The results showed that wild dog use of geographical space differed between GNP and SVC in different years and in the same years. For packs collared

in the same year movement may not cross territorial boundaries as was the case in GNP or may cross territorial boundaries, as was the case in SVC. Movement for packs collared in different years using the same geographical space showed that wild dog use the same geographical space differently where one pack would have concentrated movement in one area, another pack's movement would be dispersed. Identification of packs using the same geographical space in different years apart from confirming that wild dog can use the same territory in different years may also be a reflection of wild dog belonging to the same pack. The different patterns observed for GNP and SVC may be a result of fewer packs collared for a shorter period in GNP although it is the larger reserve, or can explain the changes wild dog have to adapt to in their use of space when there are spatial constraints such the smaller SVC reserve. Nonetheless, the results confirm that packs avoid one another's territories and show evidence of territoriality that complements the results of Woodroffe (2010). The results also showed that there is limited movement of wild dog outside reserve boundaries, indirectly confirming Woodroffe et al. (2007) and Lindsey et al. (2011)'s perceptions that wild dog are exposed to more persecution outside reserve boundaries, which leads them to avoid venturing beyond the reserve boundaries.

5.2 UTILIZATION DISTRIBUTIONS EXTENT

Each packs' UD differed in size for the same pack between the two seasons and for different packs in the same reserve in a specific year (Table 5.11). UDs size gradually increased from the 0.1-level to the 0.95-level isopleth during the hot and wet season in both reserves whereas in the cold and dry season this was only seen for SVC. In GNP, largest isopleths were 0.75-level meaning the wild dog used 75% of their UD the most. GNP's UDs were larger by 99.5 km² in the cold and dry season and 295.42 km² in the hot and wet season and SVC's UD were larger by 351.82 km² in the cold and dry season and 353.13 km² in the hot and wet season from the 0.1-level isopleth to the 0.95-level. During the cold and dry season, GNP's average total UD size was 100.24 km² and SVC's was 327.91 km². This meant SVC's average UD extents were about three times larger than GNP's even though GNP is the larger reserve. During the hot and wet season, GNP's average total UD size was 303.5 km² and in SVC's was 359.17 km². This showed that GNP's average total UDs were 203.25 km² larger in the hot and wet season and SVC's were 12.87 km² lower. This is probably because whilst in GNP the UDs were always larger in the hot and wet season, in SVC the UDs extent was larger in the cold and dry season for some packs.

Table 5.1 Total area in km² for the UD_s for each of the collared packs in GNP and SVC in both the cold and dry, and hot and wet season

	Isopleth	0.1		0.25		0.5		0.75		0.95	
		Cold and Dry	Hot and Wet	Cold and Dry	Hot and Wet	Cold and Dry	Hot and Wet	Cold and Dry	Hot and Wet	Cold and Dry	Hot and Wet
GNP	Chalanda	0.1	11.1	0.1	37.0	0.8	108.4	13.8	381.6	69.4	477.1
	Mabalauta	3.4	17.6	19.8	45.9	101.7	97.8	363.9	215.1	130.6	434.1
	Machaniwa	0.0	1.7	0.2	2.4	7.1	15.1	24.4	44.6	56.1	145.4
	Shangana	0.2	1.8	0.4	24.6	5.8	48.7	64.1	85.9	144.9	157.5
SVC	Batanai	1.8	15.9	7.4	47.0	80.0	116.6	225.6	211.9	480.2	449.6
	Bedford	0.0	2.0	0.2	11.2	4.7	56.3	46.0	178.9	281.7	541.3
	Crocodile	0.1	4.3	4.5	11.1	34.1	39.5	74.8	81.2	190.7	168.5
	Maera	0.2	6.8	9.1	27.3	96.1	82.4	308.4	197.2	404.1	600.3
	Mambira	0.2	6.1	7.6	26.3	53.5	86.8	184.3	237.3	402.4	392.6
	Mapura	0.0	4.7	0.1	16.4	30.5	55.5	114.2	114.9	353.9	257.5
	Nyarushanga	0.0	--	0.0	--	0.4	--	51.9	--	144.0	--
	Patch	4.2	6.6	15.4	26.6	80.8	75.2	268.9	170.8	310.9	307.3
	Splinters	0.4	7.4	5.2	32.6	65.0	106.2	194.1	232.2	480.8	434.8
	Star	0.0	3.1	0.1	10.0	2.1	29.3	19.2	74.1	80.3	152.7
	Tick	0.1	3.6	16.6	19.5	82.1	87.0	234.9	204.9	478.0	287.1

In the study, Mabalauta and Shangana were used to illustrate comparisons between packs as well as females and males in GNP whilst in SVC, Patch and Tick were used for comparisons between sexes, and Batanai, Crocodile, Mambira, and Mapura were used for pack comparisons. Both Mabalauta and Shangana's UD sizes gradually increased from the 0.1-level to the 0.95-level isopleth with Mabalauta's total UD_s 132.14 km² larger than Shangana. From the 0.1-level to the 0.95-level isopleths Mabalauta's UD_s were larger by 127.18 km² in the cold and dry season and 416.47 km² in the hot and wet season whereas Shangana's was larger by 144.72 km² in the cold and dry season and 155.65 km² in the hot and wet season. Mabalauta's average total UD size was 282.33 km² and Shangana's average total UD size was 151.19 km². This showed that Mabalauta's average total UD were larger by 303.56 km² in the hot and wet season and Shangana's were 12.57 km² larger (Figure 5.3). Patch and Tick's UD_s sizes gradually increased from the 0.1-level isopleth to the 0.95-level with Tick's total UD 73.44 km² larger than Patch's. Her UD_s were larger by 306.7 km² in the cold and dry season and 300.75 km² in the hot and wet season and Tick's were larger by 477.16 km² in the cold and dry season and 283.45 km² in the hot and wet season from the 0.1-level to the 0.95-level isopleths. Patch's average total UD_s size was 309.11 km² Tick's was 382.55 km², which showed that Patch's average total UD_s were 3.61 km² larger in the hot and wet season and Tick's was 190.93 km² lower (Figure 5.3).

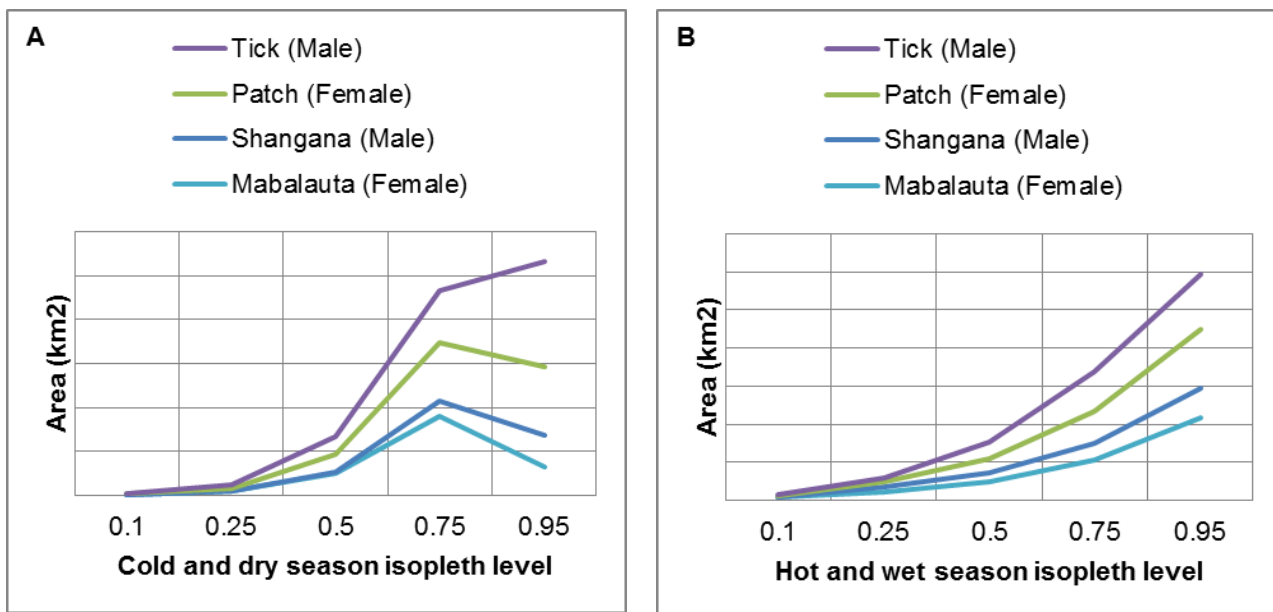


Figure 5.3 Comparison of female and males UD extents in the cold and dry (A), and hot and wet (B) season in both GNP and SVC

From the 0.1-level to the 0.95-level isopleths, Batanai, Crocodile, Mambira and Mapura’s total UD size were 30.6 km², 22.2 km², 9.9 km² and 96.4 km² smaller respectively from the cold and dry to hot and wet season (Figure 5.4).

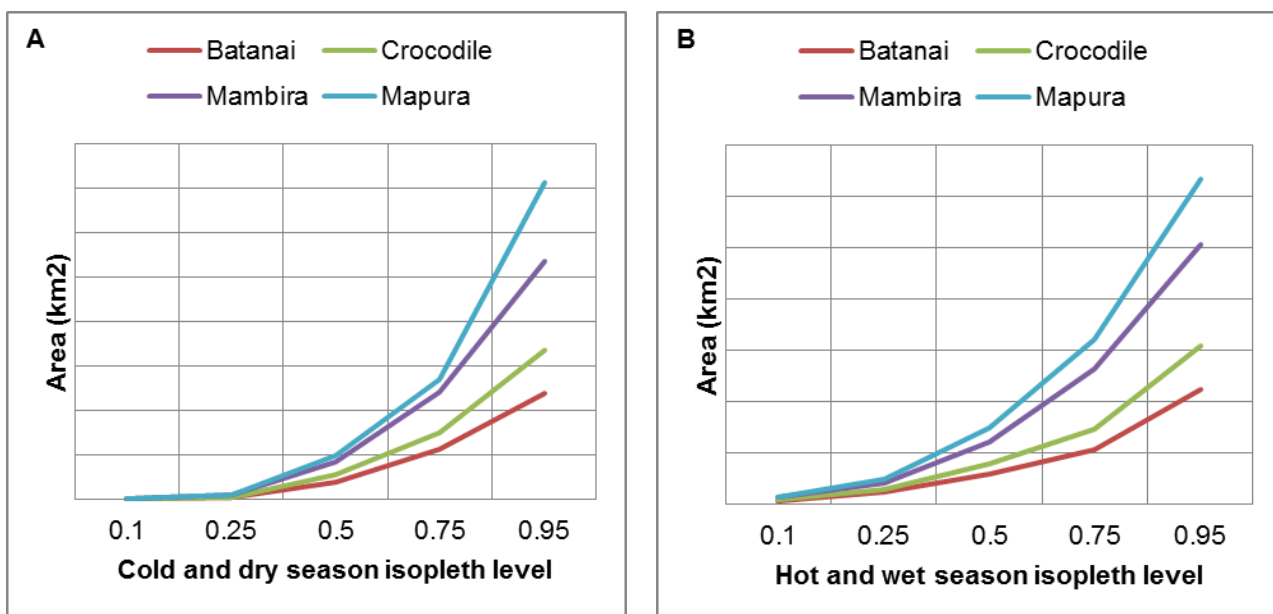


Figure 5.4 Comparison of UD extents of different packs in SVC for the cold and dry (A), and hot and wet (B) seasons

UD extents were analysed to see if there were differences between packs and sexes. The results showed that UD extents increased from the 0.1-level to the 0.95-level isopleths and that the usually cold and dry extents were smaller than the hot and wet extents up to the 0.5-level after which the larger extents differed between seasons. The study suggests that the difference in UD size is due to the denning season in the cold and dry season discussed in Chapter 4, which would lead wild dog to have centralized and clustered movement whilst they den, compared to other seasons. This was in agreement with Woodroffe's (2010) study that found UDs in the denning seasons to be smaller than in other seasons. The study also suggested that UD size might be a direct consequence of pack size where larger packs would have bigger UDs compared to smaller packs. Differences between sex extents in GNP suggested that the female wild dog had larger extents than the males; however, in SVC the male dog had the larger extents. Therefore, the study failed to draw a conclusion, as there were two instances from which to make deductions. However, the difference in UD extent did confirm Herfindal et al. (2005)'s deduction that UD extents were sex specific.

5.3 GEOGRAPHIC AND TEMPORAL DISTRIBUTIONS

In the study, Mabalauta and Shangana were used to illustrate comparisons between packs as well as females and males in GNP whilst in SVC, Patch and Tick were used for comparisons between sexes, and Batanai, Crocodile, Mambira, and Mapura were used for pack comparisons. The study illustrated wild dog UD sorted by likelihood of occurrence as wild dog geographical distribution. Each UD has five levels from the 0.1, 0.25, 0.5, 0.75 to the 0.95 levels representing the areas with the highest density of occurrence points to areas with the least density of occurrence points. The 0.1 level represented in black are the areas with the highest density of occurrence points, which form the core (central area) of the animal's home-range. Levels 0.25, 0.5 and 0.75 represented in different shades of grey show a decreasing density of occurrence points. The 0.95 level represented in white, are the areas with the lowest density of occurrence points (periphery of the home-range). Temporal distributions were explained using measures of re-visitation and durations of stay per visit. Areas that were visited infrequently for short periods were represented with white points and areas visited infrequently for long periods were represented with light grey points. Areas visited frequently for short periods were represented with dark grey points and areas visited frequently for long periods were represented with black points. Geographic and temporal distributions results for Chalanda, Machaniwa, Bedford, Maera, Nyarushanga, Splinters, and Star are shown in Appendix C. The relationship between UD level, re-visitation rate, and duration of stay varied per pack and in

different seasons in both GNP and SVC and this is discussed further below. This section presents the geographic and temporal distributions of individuals Mabalauta, Shangana, Patch and Tick, and Batanai, Crocodile, Mambira, and Mapura packs.

5.3.1 UDs and re-visitation rates and duration of stay in GNP

Mabalauta had three core areas in south-east GNP during the cold and dry season two of which were 0.1-level and one 0.25-level isopleths (Figure 5.5). In addition, she also had a combination of 0.5-level and 0.75-level isopleths in southern GNP and her UD, which extended to the far north, was in the 0.95-level isopleth. In the hot and wet season, she still had three core areas two of which were 0.25-level and one 0.1-level isopleths. In this season, she also had distribution in 0.5-level to 0.95-level isopleths, but this was confined to southern GNP. This means that Mabalauta's core areas were fewer in the hot and wet season as well as the extent of the 0.95-level isopleth (Figure 5.5).

During the cold and dry season, Mabalauta had mostly high re-visitations with short durations in southern GNP where majority of her movement clustered. In central and northern GNP, her visits had low frequency and lasted for short periods. Mabalauta ventured outside the park's boundary and whilst movements in northern GNP were characterised by low re-visitation and short durations, movements outside GNP in the south were infrequent visits for long durations. In the hot and wet season, her movement became concentrated in southern GNP. She frequently visited areas to the south-west of her UD where her durations of stay varied. To the north-west of her UD, Mabalauta's infrequent visits were for short durations whereas her infrequent visits to the north-east and south were for long durations (Figure 5.5). Her mean re-visitation changed by 1.27 times from cold and dry to the hot and wet season whereas her duration of stay changed by one day. Seasonal changes in her minimums were minor, but changes in the maximums show different uses of space. Her maximum re-visitation rate was 10 times lower in the hot and wet season and her duration of stays were 6 days shorter. The larger isopleths levels had few visits that lasted for short durations and the core areas generally had high re-visitation and short durations during the cold and dry season. In the hot and wet season, this pattern changed with infrequent visits lasting for long durations being more common in the 0.5-level to 0.75-level isopleths. Frequent visits with long durations were in the 0.1-level and infrequent visits for short periods were more to the south in 0.25-level isopleths (Figure 5.5).

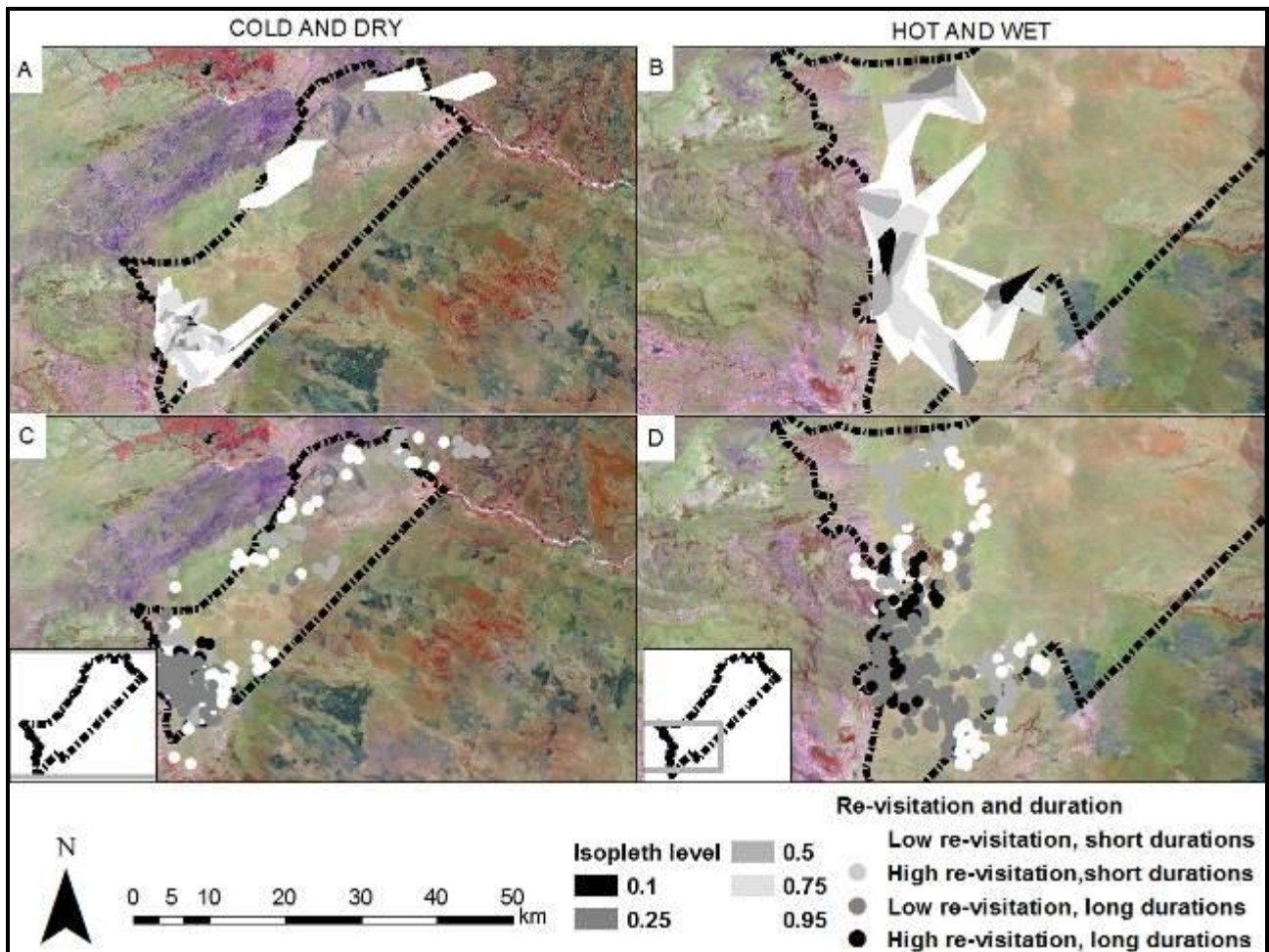


Figure 5.5 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Mabalauta (Female) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

Shangana had one core area in the cold and dry season, in north-west GNP. The remainder of his UD was in 0.5-level to 0.95-level isopleths with the core area surrounded by 0.5-level and the distribution to the south, being mostly 0.95-level isopleths. During the hot and wet season Shangana's core areas increased in both number and size to three, two of which were to the south of the UD in the 0.25-level and one was north of his UD that had both 0.1-level and 0.25-level isopleths. Similar to the cold and dry season, these core areas were also surrounded by areas in 0.5-level to 0.75-level isopleths and his UD outside the park's boundary was in the 0.95-level isopleth (Figure 5.6).

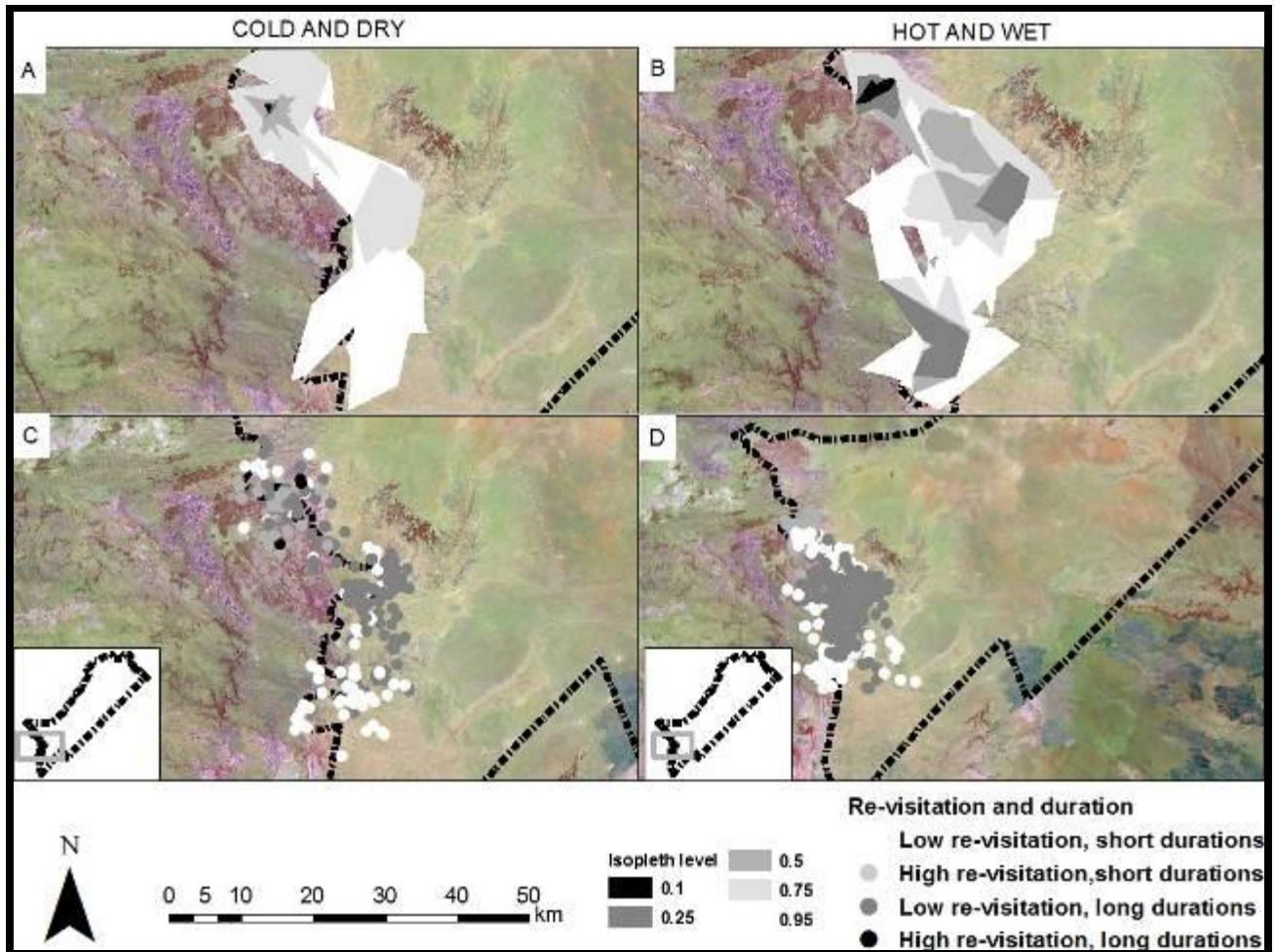


Figure 5.6 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Shangana (Male) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

In the cold and dry season, Shangana had infrequent visits for short periods south of his UD whilst in the centre of his UD extent; he made infrequent visits for long periods. Majority of his visits to the north of his UD were a combination of frequent and infrequent visits that lasted for long periods. His movement outside GNP was characterised by infrequent visits for short periods. To the south of his UD, his visits were frequent and altered between long and short durations. This temporal distribution changed in the hot and wet season where Shangana's visits in the core of his UD were infrequent and lasted for short periods. Shangana had minor seasonal changes in his minimum and maximum re-visitation and duration of stay. The maximum re-visitation changed by three visits from the cold and dry season to the hot and wet season, and the duration of stay was four days shorter. However, the mean values showed large differences in re-visitation rate and duration of stay where his mean re-visitation was 8.5 visits less in the hot and wet season and his duration of stay was 13 days shorter in the hot and wet season. During the cold and dry season, his

core area to the south of his UD had frequent visits for long periods whilst the rest of his UD had few visits with short durations in the 0.95-level isopleth. South of his UD, Shangana had infrequent visits for long durations in 0.5-level to 0.75-level isopleths. This semi-structured pattern changed in the hot and wet season where there was an increase in few visits with long durations both north and south of the previous core area. The infrequent visits spanned from the 0.1-level to 0.75-level isopleths and, infrequent visits for short periods in the 0.95-level isopleth increased on his UD periphery (Figure 5.6).

5.3.2 UDs and re-visitation rates and duration of stay in SVC

Patch had five core areas in north-east SVC and another one in the north-west during the cold and dry season. Three of these core areas were 0.1-level and the rest were 0.25-level isopleths. Majority of the distributions in the 0.5-level to 0.75-level isopleths surrounded core areas although in the south-west of her UD these levels were also surrounded by distributions in the 0.95-level isopleth. During the hot and wet season, Patch still had five core areas two of which were 0.25-level and three were 0.1-level isopleths in their centres but, were surrounded by distribution 0.25-level isopleths. However, these isopleth levels were visually larger and the 0.1-level isopleth core areas, moved to the south west of her UD. Although similar to the cold and dry season, the 0.5-level to 0.75-level isopleths surrounded the core areas; the 0.95-level isopleth was mostly in the north-west (Figure 5.7).

During the cold and dry season, Patch's frequent visits for short periods north-east were surrounded by areas that she frequently visited for long periods to the west and south. South of her UD, her visits were infrequent for long durations whereas to the north-west of her UD, she made infrequent visits for short durations. During the hot and wet season, Patch's movement changed to infrequent visits for long durations to the northeast of her UD. Her central distribution had frequent visits for long short periods whilst to the south-west she had frequent visits that would last for long periods (Figure 5.7). Patch's minimum re-visitation rates and durations of stay did not differ much between the two seasons. Maximum and mean duration of stay also did not show large variations in durations of stay where the maximum re-visitation was three days shorter in the hot and wet season and mean duration was two days longer. However, her seasonal maximum and mean re-visitation

rates showed more variation where maximum re-visitation was 31 visits less in the hot and wet season and mean re-visitation was 24.6 visits less. She had frequent visits that lasted for short durations in the 0.1-level to 0.25-level isopleths whereas in the 0.5-level to 0.75-level isopleths, she had a combination of frequent and infrequent visits lasting for long periods. In the 0.95-level isopleth, Patch had short infrequent visits. During the hot and wet season, she had frequent visits for short durations in the core area. In the 0.1-level isopleth in the south-west of her UD, she had infrequent visits for long and short periods in 0.5-level to 0.95-level isopleths (Figure 5.7).

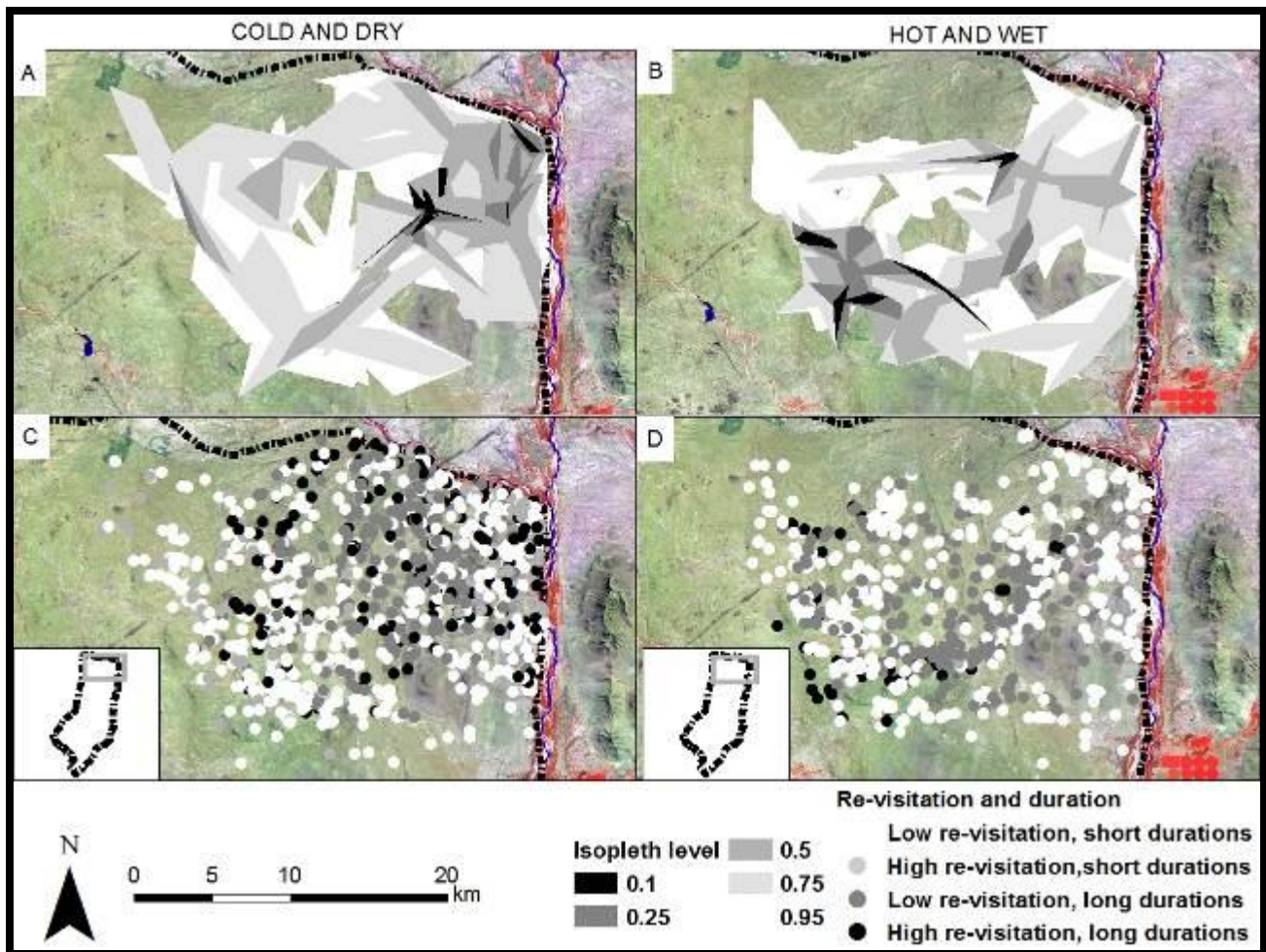


Figure 5.7 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Patch (Female) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

Tick's UD in the cold and dry season seemed divided into two sections with one in the north-east whose core area was 0.25-level isopleth where his den was located, and another in the south-west whose core area was 0.5-level isopleth. These two areas were connected by an area he used in the

0.95-level isopleth. His core area in the north of his UD was surrounded by 0.5-level to 0.75-level isopleths whilst his distribution in the south-west was surrounded by 0.75-level to 0.95-level isopleths. The secondary distribution in the south was surrounded less by distribution in 0.95-level isopleth compared to the distribution in the north which was mostly 0.95-level isopleth although, the northern distribution had the core area. In the hot and wet season, Tick's movement became condensed and his core areas raised to nine, four of which were 0.1-level isopleths concentrated in the north-east and one in the south-west of his UD. Unlike in the cold and dry season, these core areas were randomly surrounded by 0.5-level to 0.95-level isopleths (Figure 5.8).

Tick's re-visitation rate and durations of stay during the cold and dry season followed a semi-structured pattern where to the north-east of his UD, he had frequent visits for short periods. Just south of these areas, his visits became frequent for long durations whereas to the west, his visits were infrequent for long periods. Further south of his UD, Tick had infrequent visits for long and short periods. In the hot and wet season Tick had a matrix of areas where he alternated between frequent and infrequent visits for short periods in the north-east of his UD. Tick consistently stayed for long periods in his frequent visits south-west of his UD and he stayed for long periods in his infrequent visits to the south-east and north-east peripheries of his UDs (Figure 5.8). Tick's seasonal minimum, maximum, and mean values did not show much change between the two seasons for both re-visitation and duration of stay. Maximum re-visitation rate was 13 visits less in the hot and wet season whilst maximum duration of stay was three days shorter. Mean re-visitation was four visits more and mean duration was two days shorter. During the cold and dry season, Tick had areas of high re-visitation and long duration in 0.25-level isopleth whilst in 0.75-level to 0.95-level isopleths; his visits became infrequent for long periods. This was similar in the south of his UDs where his infrequent visits for long periods in 0.5-level to 0.75-level isopleths. During the hot and wet season, his temporal distribution became dispersed throughout his UD levels. In the 0.1-level to 0.75-level isopleths, his visits had a mixture of frequent visits for long and short periods and infrequent visits for short periods. However, in the 0.95-level isopleth, his infrequent visits were for long durations (Figure 5.8).

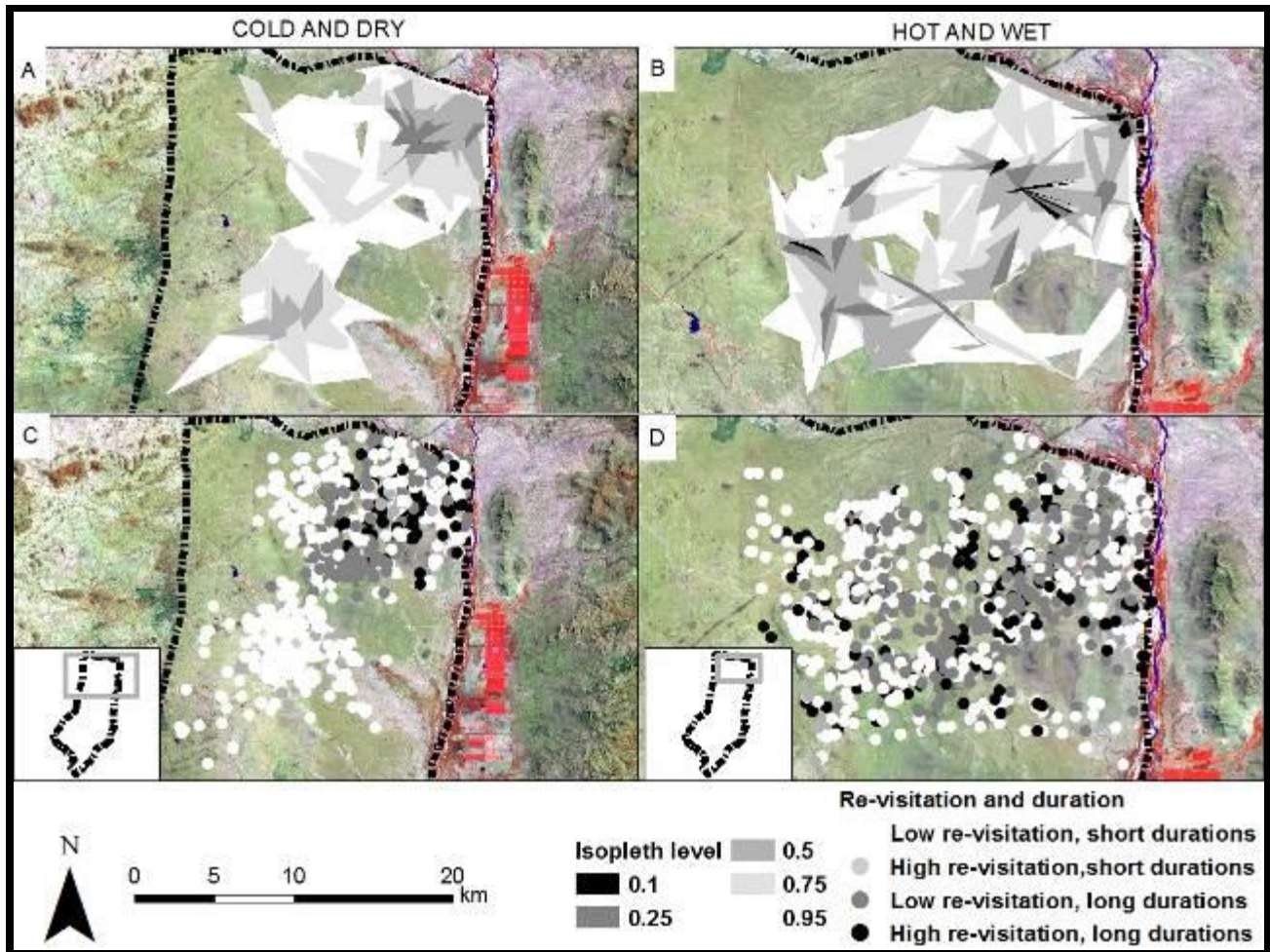


Figure 5.8 Isopleths showing highest density of occurrence points and re-visitation rates and durations of stay for the cold and dry (A & C) and hot and wet season (B & D) for Tick (Male) in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

During the cold and dry season, Batanai's distribution was concentrated to the south of the pack's UD where its movement was mostly in 0.5-level to 0.75-levels surrounded by 0.95-level isopleths, except for the core area in the 0.25-level isopleth. Secondary distribution to the north of the UD also had similar distribution. Crocodile had one core area in the 0.25-level isopleth to the south of the packs' UD, which was surrounded by 0.5-level to 0.75-level isopleth distributions. Most of the distribution in the 0.95-level isopleth was to the far east and west of the packs' UD. Mambira had two core 0.25-level isopleth areas that were surrounded by 0.5-level to 0.75-level isopleths, which developed into the 0.95-level in the north-west of the packs' UD. Mapura had one core 0.25-level isopleth area in the cold and dry season, surrounded by distribution in the 0.5-level to 0.75-level isopleths in the centre of its distribution whilst distribution far south of the UD was mostly in the 0.95-level isopleth. During this season, den locations identified for Batanai, Mambira and Mapura were all in the core areas of the packs' UD. During the hot and wet season all four packs had more

core areas in their UD in the 0.1-level to 0.25-level isopleths all surrounded by distributions in the 0.5-level to 0.95-level isopleth (Figure 5.9).

In the cold and dry season, Batanai and Mapura had frequent visits for long periods in their core areas whilst Crocodile and Mambira had frequent visits for short periods. In the hot and wet season, these patterns changed per pack. Batanai's movements were characterised by frequent visits lasting long in the centre of the packs' UD and surrounding locations were characterised by infrequent visits for short periods. Mapura had infrequent visits for long periods in the north of the pack's UD in the hot and wet season but in the south, there were variations in re-visitation rates and duration of stay. This variation was also observed for Crocodile and Mambira whose distribution changed from somewhat structured patterns in the cold and dry season, to matrices of areas with infrequent visits lasting long or short periods throughout their UD. Mambira had movements outside SVCs borders and whilst in the cold and dry season, some of the visits were infrequent for long periods, in the hot and wet season, the visits alternated in frequency, but were always for short durations (Figure 5.9). There is further evidence of the "zones of agreed use" in these packs where Crocodile and Mapura had areas where their UD overlapped in the hot and wet season, but with the lowest probability of occurrence for both packs.

Seasonal minimum re-visitation rates and durations of stay were not very different compared to maximums and means. Re-visitation for Batanai and Mapura was 29 and 23 visits less respectively whilst Mambira had 9 more visits in the hot and wet season and Crocodiles' remained the same. Resulting mean re-visitation rate for Batanai and Mapura was 2.2 and 52.7 visits less whilst Crocodile and Mambira's visits were 6.2 and 3.6 more in the hot and wet season. Maximum duration of stay for Batanai, Crocodile, Mambira, and Mapura's was 10, 13, 13, and 14 days shorter respectively in the hot and wet season. Therefore, mean duration for Batanai, Crocodile and Mambira was 9, 13 and 9 visits less respectively from the cold and dry to hot and wet season, whereas Mapura's was consistent in both seasons

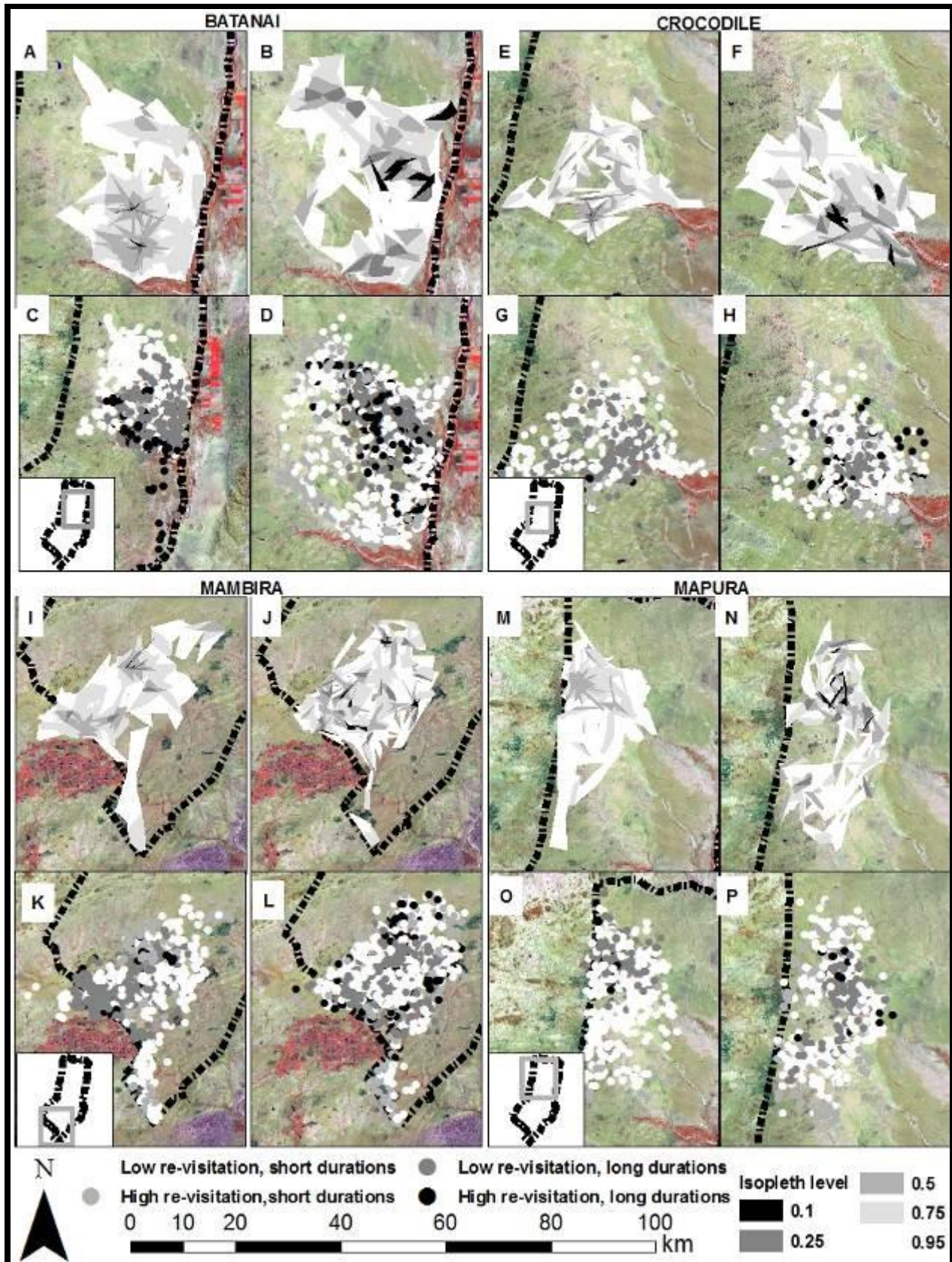


Figure 5.9 Isopleths for Batanaï, Crocodile, Mambira, and Mapura in the cold and dry season (A, E, I and K) and the hot and wet season (B, F, J and L) as well as re-visitation rates and durations of stay for the cold and dry season (C, G, M and O) and the hot and wet season (D, H, N and P) in SVC. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

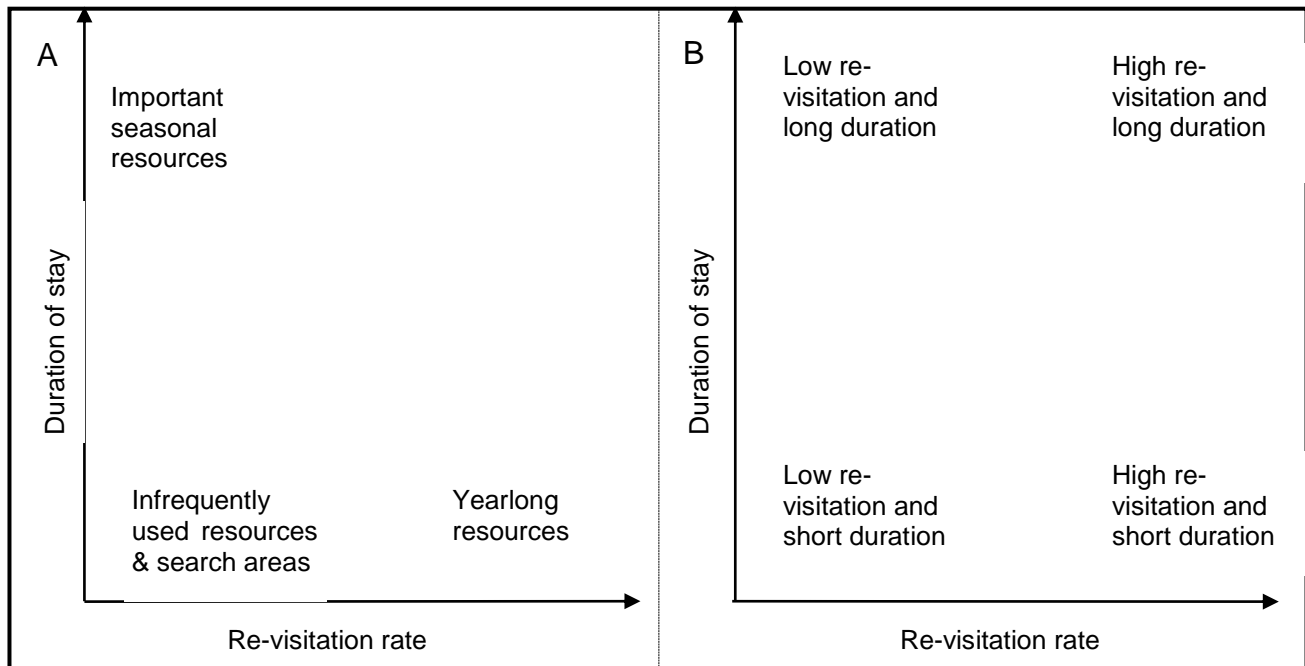
5.3.3 Relationship between geographic and temporal distributions

Wild dog geographic and temporal distributions were assessed in the study to understand wild dog use of space in different seasons for males, females and packs. Based on prior understanding, the study assumed that the core areas would be the areas that wild dog used most in space for their different ecological functions. All the packs in the study showed that in the cold and dry season when they denned, they had fewer core areas, which concentrated around den locations. During the hot and wet season there were more core areas randomly spread out through their UD. Therefore, the study suggests that the few core areas in the cold and dry season were because of the denning season where wild dog would use the area with the den location most for three consecutive months. This confirmed Lindsey et al. (2011)'s study that also suggested that during the denning season, the area wild dog use most is the den site. However, the study was not able to verify this theory for wild dog in GNP as no den sites were identified. The study assumed that the numerous core areas in the hot and wet season were a result of predation avoidance (McNutt & Silk 2008; Swanson et al. 2014) and larger isopleth levels were consequences of wild dog moving from their home-range to hunt prey (Cloutier & Packard 2014) and possibly look for mating partners (Kratt & Kratt 2013).

Wild dog use of resources in space was explained using a species re-visitation rate, duration of stay and resources described by T-LoCoH (Figure 5.10A) and deducing how they were identified using temporal distribution patterns (Figure 5.10B) as used in this study. T-LoCoH explained three of the patterns namely high re-visitations with short durations as areas with yearlong resources, low re-visitations with short durations as areas with infrequently used resources and search areas, and low re-visitations with long durations as areas with seasonal resources (Lyons, Turner & Getz 2013). In addition, the study made a fourth observation of areas that had high re-visitations with long durations and assumed these were areas with yearlong resources.

The study confirmed that wild dog temporal use of space is based on availability of resources as well as persecution and predator avoidance, but that due to its complex ecology there is not a clear-cut relationship between resources, re-visitation, and duration of stay. Appendix D shows wild dog re-visitation rates and duration of stay plotted using isopleths colour code and corresponding maps for all packs in GNP and SVC in different seasons. During the cold and dry season, core areas had low re-visitation with varied durations as compared to larger UDs, which had high re-visitations with short durations. In the hot and wet season, core areas still had lower re-visitation but were now

characterised by long durations. Larger isopleths had higher re-visitations with shorter durations such that the relationship between the re-visitation rates and the UD levels then translates loosely to: “the lower the UD level, the lower the re-visitation rate” but, duration of stay is varied.



Source: Lyons, Turner & Getz (2013:7)

Figure 5.10 Relationship between a species re-visitation rate, duration of stay and the resources it uses in its UDs where A is the explanation given by T-LoCoH and B is the interpretation used by the study

The study assumed temporal distributions were based on wild dog having different ecological roles in their packs. In denning seasons wild dog that hunted and regurgitated meat for the pups would have different temporal distributions to those that participated in pup guarding. Therefore, the study explained wild dog with high re-visitation rates for short durations in core areas as hunters, that frequently visited den locations to make food provisions for the pups and adult females at the den location but did not stay for long periods (Pole et al. 2004, Burrows 2011). Wild dog with low re-visitations and long durations in core areas were assumed to be involved in pup guarding which leads them to visit dens infrequently but stay for long periods (Lindsey et al. 2011).

Outside of the denning season, the study assumed the core areas with long durations compared to larger UD levels were confirmation of wild dog searching for prey in high-risk areas. Therefore, wild dog stay longer in the core areas where it is safe and move to the larger isopleth levels to gather resources. Wild dog infrequently used resources and search areas being characterised by low re-visitation and short durations can be explained by their hunting behaviour where wild dog unlike

other large carnivores do not take a long time to eat their kill and instead eat quickly and digest later (Gusset & Macdonald 2010). The study also assumed areas with high re-visitation rates and long durations of stay were areas that wild dog stay in for long periods and re-visit often because they are “safe” from both persecution by humans and predators (Woodroffe & Donnelly 2011).

Comparisons between the sexes showed similarities between Shangana and Tick, and Mabalauta and Patch that suggest whilst both males and females have fewer core areas in the cold and dry season, female wild dog always had more core areas in the cold and dry season than males. This may be explained by both females being pup guards such that their patterns clearly reflected wild dog changing den sites (Whittington-Jones, Parker & Davies-Mostert 2011). However, the study could not verify this assumption. In addition, the study also found that males had semi-structured movement patterns in the cold and dry season where they made numerous visits to their core areas whereas females’ movement was less structured. This may suggest that female wild dog are more sensitive to predators as wild dog do not stay at kills for long periods (Mills & Gorman 1997) like other large carnivores. Instead, their longest stays are in areas where they “rest and play” where there is lower risk from predators (Darnel et al. 2014). This confirmed that UD size can differ based on sex (Herfindal et al. 2005). The UD’s explanations based on different sexes could not conclude general patterns for wild dog due to the small sample size.

CHAPTER 6: WILD DOG PROBABILITY DISTRIBUTION

Wild dog geographic and temporal distributions were used as building blocks in the study to map wild dog probability distribution by means of various models. The distribution model uses the ecological niche theory as the areas that a species can also exist in (Soberón & Peterson 2005). MaxEnt was the best-suited species distribution model (SDM) from the models run in BIOMOD and the MaxEnt model results showed that majority of the reserves in south-eastern Zimbabwe potentially have suitable habitat for wild dog. Therefore, Chapter six shows the results of a wild dog distribution model built using MaxEnt as well as results from GLM, GAM and MaxEnt SDMs run in BIOMOD for wild dog distribution in GNP, SVC and areas outside the reserves. The chapter presents models and outputs for each reserve and the information based on packs is in Appendix E to Appendix J.

6.1 ACCESSIBLE AREAS TO WILD DOG

BIOMOD results for GAM, GLM and MaxEnt, showed that MaxEnt had the highest Kappa and ROC AUC values for the models replicated over 15 times (Figure 6.1) both within and outside the reserves. This confirmed that MaxEnt was the best-suited method for the study. For both Kappa and ROC AUC values, the closer a value is to one, the higher the accuracy of the model (Bradley 1997; Rakotomamonjy 2004; Field 2007; Peterson, Papes & Soberón 2008). In all the models run, the Kappa values were lower than the ROC AUC's. This did not mean low model accuracies, but was because Kappa calculates accuracy using number of samples per class and ROC AUC uses a classifier system and threshold.

The study found that all three models had high ROC AUC values making each of them appropriate for wild dog data. Between the three models, MaxEnt had the highest values making it the most suitable model with GAM values slightly lower (Figure 6.1). This was most likely because wild dog locality points were presence-only data which is an advantage of using MaxEnt (Araújo & Guisan 2006; Elith & Leathwick 2009) as MaxEnt's predictions have been found to have better accuracy than presence/pseudo-absence models when tested against real presence/absence data (Elith et al. 2006; Austin 2007; Franklin et al. 2009). MaxEnt as the highest performing model was selected for accuracy testing.

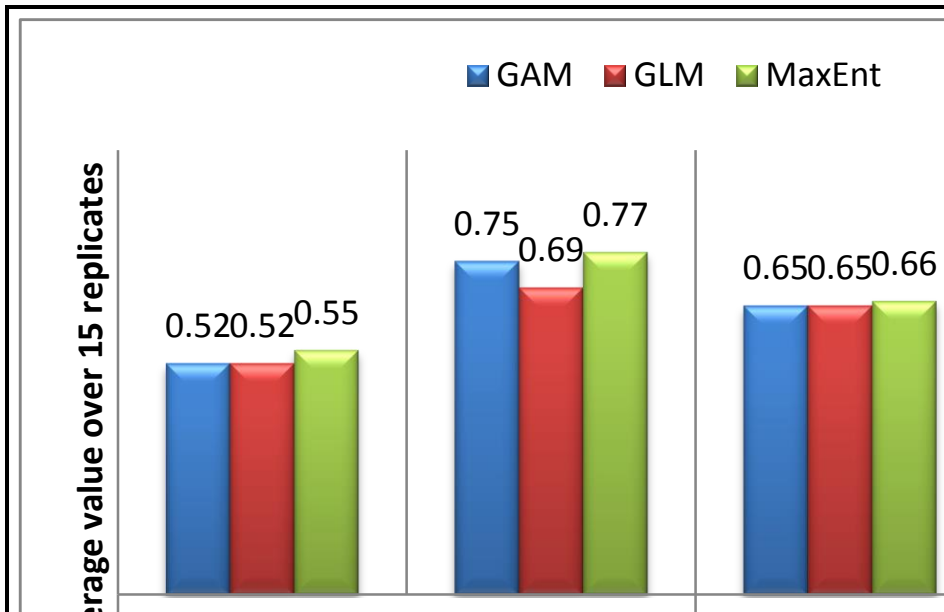
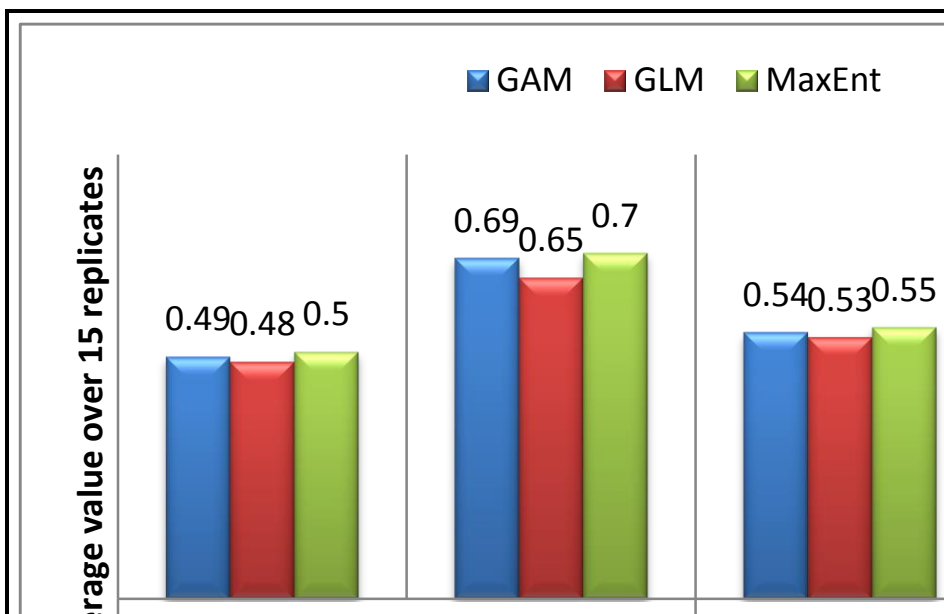
A: Gonarezhou National Park**B: Savè Valley Conservancy**

Figure 6.1 BIOMOD Kappa and ROC AUC results for GAM, GLM and MaxEnt SDM over 15 replicates within and outside the reserves for (a) GNP and (b) SVC. Note higher Kappa and ROC AUC values represent better model accuracy

6.2 VARIABLES INFLUENCING MOVEMENT AND DISTRIBUTION

Wild dog movement and distribution patterns are influenced by several variables, which have been discussed in literature as either direct influences, or indirect influences. Direct influences are those which affect wild dog themselves (Pressey et al. 2007) whilst indirect influences affect wild dog

environment; or prey and predator behaviours (Caley, Tennant & Hood 2011). Variables that influence wild dog movement and distribution patterns are either biotic or abiotic (Kearney & Porter 2009) and studying these variables assist the ecological niche theory in partly identifying the areas with the right environment that are accessible to the species (Soberón & Peterson 2005).

6.2.1 Biotic variables

The study defined biotic variables as interactions that the wild dogs have because of human influences that affect wild dog movement and distribution patterns in their UD. Three variables were discussed in the study, namely human settlements, roads, and distance from reserve boundaries but there are other factors that influence wild dog movement and distribution patterns such as prey and predator densities. The study found that of the three biotic variables studied, wild dog responded differently to each in GNP and SVC.

6.2.1.1 Human settlements

In GNP, wild dog movement avoided close proximity to the human settlements in both seasons as less than 1% of their movement was within 5 km of the human settlements. Wild dog movement was 3.8% and 8.3% more in the cold and dry season and hot and wet season respectively from within 5 km to within 10 km. In the hot and wet season, their movement was 12.4% more from within 10 km to within 20 km of the human settlements, which showed that their movement increased with distance from human settlements. More than two thirds of their movement was more than 20 km from the human settlements in both seasons but their avoidance in the cold and dry season was higher by 8.5%. This suggests that wild dog move closer to human influences in the hot and wet season (Figure 6.2). Less than a tenth of wild dog movement in SVC was more than 20 km from human influences in both seasons. This may suggest that wild dog in SVC do not avoid human influences or that they contend with human-wild dog conflict within the conservancy borders to avoid higher risks. During the cold and dry season, just less than a quarter of the movement was within 5 km of the human influences that was 3.9% and 14.1% more than movement within 10 km and 20 km from human influences respectively. During the hot and wet season, just above a third was within 5 km of the human settlements, 13.7% less than movement within 10 km and 21.2% more than within 20 km. This illustrated two patterns firstly, movement closest to the human

influences was higher in the hot and wet season, and secondly, there was more movement within 10 km of the human settlements in the cold and dry season compared to the hot and wet season (Figure 6.2).

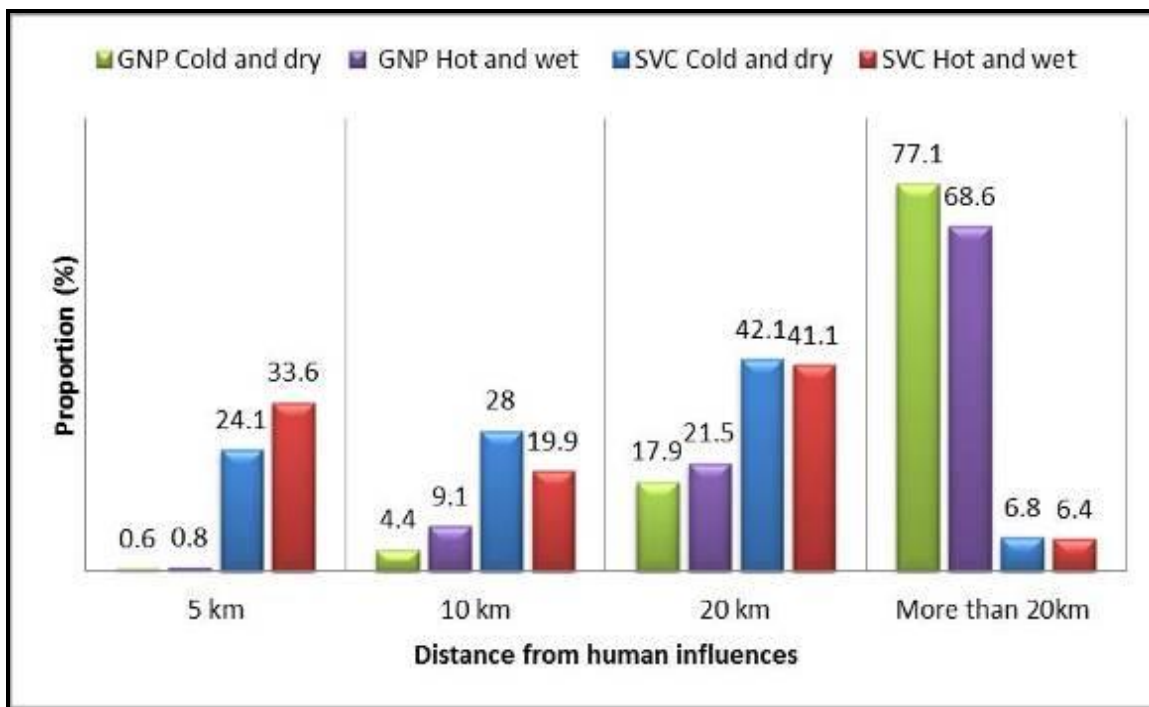


Figure 6.2 GNP and SVC proportions of wild dog locality points in 5 to 20 km buffer distances from human settlements for the cold and dry and hot and wet seasons

Mabalauta's movement within 10 km and more than 20 km from the human influences was 28.5% more in the hot and wet season. Shangana's movement more than 20 km from the human influences was 30.4% less and he had about twice his movement within 20 km of the human influences in the hot and wet season. During the cold and dry season, Shangana's movement more than 20 km from the human settlements was 25.6% greater than Mabalauta's and her movement within 5 km was greater than Shangana's which suggests females move closer to human influences than males (Figure 6.3). Patch's movement 20 km from the human influences was 9.5% more in the cold and dry season. Tick, had little variation between seasons but he moved closer to the human influences in the cold and dry season than the hot and wet season. Patch and Tick did not have major differences in their movement patterns from human influences except in the hot and wet season where Patch's movement within 10 km was greater than Tick's by 6.3% and Tick's movement within 20 km was 6.8% more than Patch's (Figure 6.3).

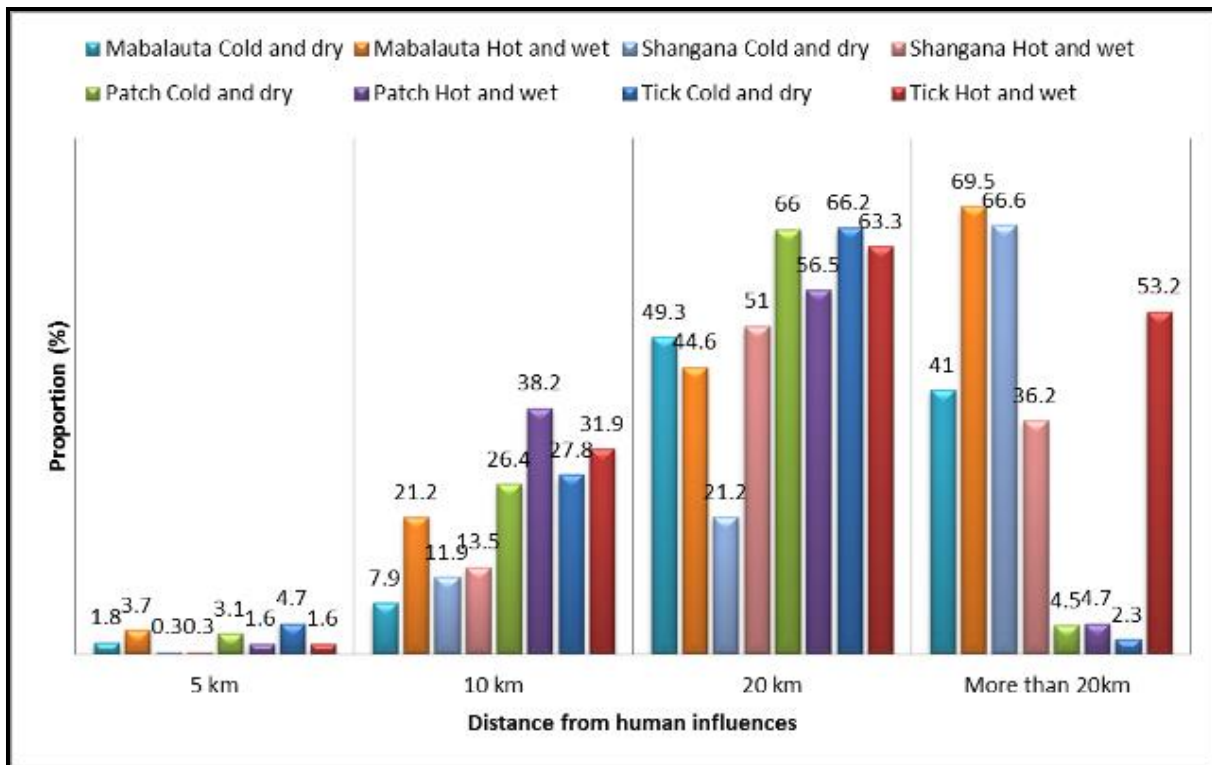


Figure 6.3 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from human settlements for the cold and dry and hot and wet seasons in both GNP and SVC

Human settlements were assessed to determine whether they were a positive or negative factor to wild dog movement and distribution patterns. The results suggest that this influence is reserve related as in GNP wild dog avoided human settlements whereas in SVC they did not avoid them as much. Movement in GNP confirmed Woodroffe (2010)'s findings that wild dog prefer areas with low human density and zoned settlement. Their selective movement around human settlements confirmed that wild dog are occasionally forced to move close to threats due to the presence of a crucial resource such as prey or protection from predators. This illustrates that co-existence of animals and humans are a characteristic of reserves (Goldman 2009; Mbizah et al. 2014) because human settlements affect wild dog distribution patterns due to human-wildlife conflict (Lindsey et al. 2011). However, GNP's relationship between wild dog and human settlements may be biased because of the few wild dogs that were collared in the park.

The results in SVC, confirmed that whilst wild dog generally avoid human settlements, they could survive in human dominated landscapes (Andrew, Wulder & Coops 2011) where they occasionally move their territories to areas where there is higher reproductive success even though there are higher rates of mortality caused by humans (Mills & Gorman 1997; van der Meer et al. 2013).

SVC's patterns also confirmed that wild dog might be more wary of persecution outside the reserve borders (Hayward et al. 2006) such that they contend with human-wild dog conflict inside reserve borders than higher risk outside. In addition, the preference of wild dog in SVC to stay within the conservancy borders may be due to conservation efforts, which have reduced persecution by humans. Finally, the study assessed human settlements to determine whether different sexes responded to their presence in different ways. The results suggest that in GNP, the females move closer to human settlements whereas in SVC, there were no major differences between the male and females' patterns.

6.2.1.2 Roads

More than two thirds of wild dog movements in GNP were within 5 km of the roads whilst there was very little movement more than 20 km from the roads. During the cold and dry season, movement within 10 km was close to two thirds less from within 5 km and movement within 20 km was 20.7% more from within 10 km. During the hot and wet season, movement within 10 km was just less than two thirds less from within 5 km and movement within 20 km was 1.8% less from within 10 km. Wild dog movement was 5.5% more within 5 km and was higher more than 20 km from the roads more in the hot and wet season. In addition, their movement within 10 km was 6.5% more and 16% less within 20 km of the roads in the hot and wet season. Therefore, wild dog move closer to roads in the hot and wet season than they do in the cold and dry season (Figure 6.4). In SVC, wild dog seemed to be impartial to the presence of the roads, as their movement was almost evenly spaced out in each buffer distance for both seasons and movement more than 20 km from the roads was less than a tenth in the cold and dry season, and less than a fifth in the hot and wet season. Majority of wild dog movement in the cold and dry season was within 5 km of the roads, which was 16.9% less within 10 km and was 13.4% more within 20 km. During the hot and wet season, majority of the movement was within 20 km of the roads. Movement within 10 km was 9.1% less than within 5 km whilst movement within 20 km was 16.3% more from within 10 km. The movement in the cold and dry season was higher within 5 km and more than 20 km from the roads whilst there was more movement within 10 and 20 km from the roads by 3.2% and 6.1% respectively in the hot and wet season (Figure 6.4).

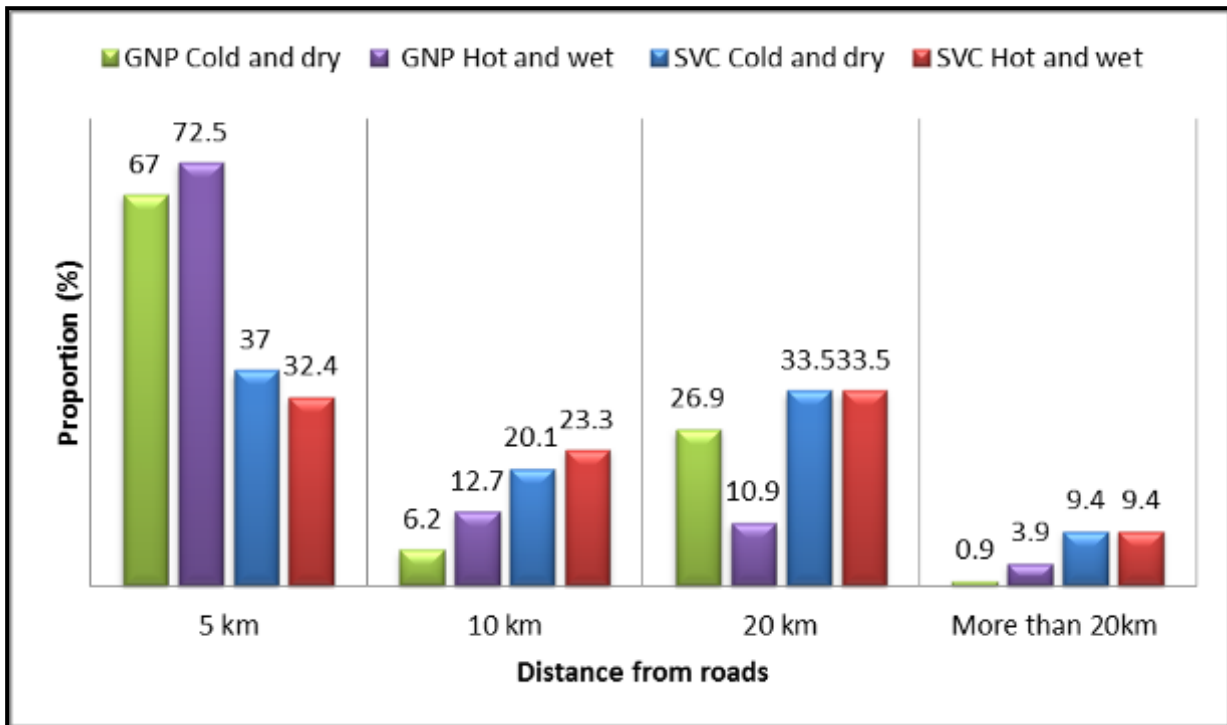


Figure 6.4 GNP and SVC proportions of wild dog locality points in 5 to 20 km buffer distances from roads for the cold and dry and hot and wet seasons

Mabalauta's movement was slightly lower in the hot and wet season within 10 km of the roads. She had more movement within 20 km and more than 20 km from the roads in the cold and dry season than in the hot and wet season. Shangana's movement within 5 km of the roads was 5.4% less in the hot and wet season whilst his movement within 10 km was higher by the same margin. In both seasons, Mabalauta's movement was lower than Shangana's within 5 km of the roads otherwise; she consistently had more movement more than 5 km from the roads (Figure 6.5). Patch's movement was 2.6% less from the cold and dry to hot and wet season and was slightly higher more than 20 km from the roads respectively. Tick's movement, was less by 19.3% and 5.1% within 5 km and within 10 km of the roads whilst it was higher by 21.5% and 3.2% within 20 km and more than 20 km from the roads in the hot and wet season. During the cold and dry season, Patch and Tick did not have major differences in their movement patterns from the roads but in the hot and wet season Patch's movement within 5 km of the roads was about eight times more than Ticks' and his movement within 20 km of the roads was 17.1% more than Patch's (Figure 6.5).

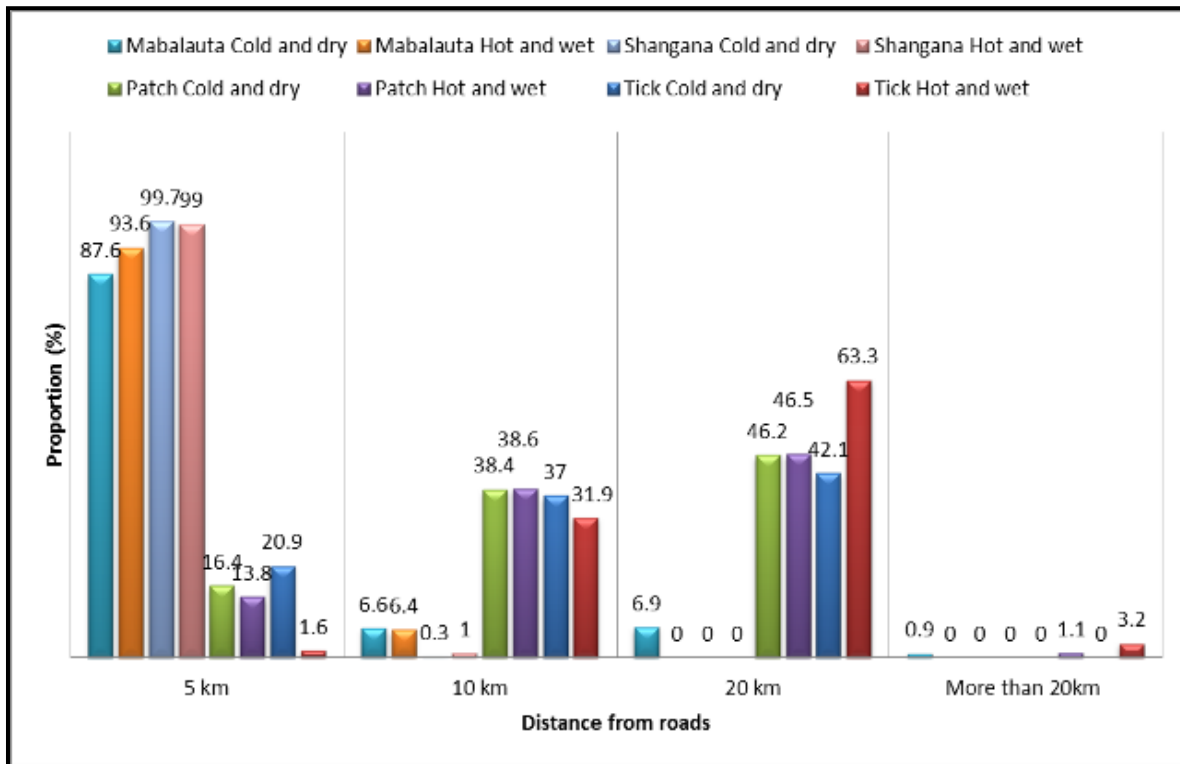


Figure 6.5 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from roads for the cold and dry and hot and wet seasons in both GNP and SVC

Roads (Figure 3.4) were assessed to determine if their influence on wild dog movement and distribution was positive or negative especially because improved networks make reserves accessible, but, increase habitat fragmentation (Buettner et al. 2007). The results showed that generally, wild dog do not perceive the roads as barriers in both GNP and SVC, but in GNP their movement close to roads is higher than in SVC. This difference is likely explained by there being more collared wild dog in SVC than in GNP such that the patterns differ. In addition, SVC's movement may be due to heavier and more frequent traffic in the hot and wet season due to the presence of tourists as opposed to the cold and dry season (Munthali 2007). Nonetheless, the proximity to roads then questions the understanding that wild dog generally avoid roads in reserves (Andrew, Wulder & Coops 2011) due to factors such as road kill (Lindsey et al. 2011), persecution during hunting trips (Woodroffe et al. 2007; Becker et al. 2012) and harassment by people from cars (Rasmussen & Macdonald 2011). The study failed to confirm if wild dog pass the roads at certain times when traffic will be presumably low as found by Bennet & Saunders (2010), because the time of movement in proximity to the roads was not assessed. The study also assessed whether there were sex specific responses of wild dog to the presence of the roads and found that in GNP, females

were more conscious of their movement close to roads as compared to males. However, in SVC there were no major differences.

6.2.1.3 Reserve boundary

During the cold and dry season, wild dog movement within 10 km of the park was 98.9% less than the movement within 5 km whilst movement within 20 km was 0.1% more than within 10 km and movement more than 20 km was 0.3% less than movement within 20 km of the park. During the hot and wet season, movement within 10 km of the park was 99.6% less than movement within 5 km. Wild dog in GNP did not move very far from the boundary of the park in both seasons. Movement within 5 km of the park was higher in the hot and wet season by 0.6% whereas movement within 10 km was higher in the cold and dry season by 0.1%. More than 10 km from the boundary movement was present in the cold and dry season (Figure 6.6). In SVC, wild dog also mostly had their movement close to the conservancy's boundary. Within 5 km of the conservancy, movement in the hot and wet season was higher by 0.4% but more than 5 km from the conservancy, the cold and dry season had more movement than the hot and wet season. During the cold and dry season, movement within 10 km of the conservancy was 99.5% less than movement within 5 km and movement within 20 km was 0.1% less than movement within 10 km. During the hot and wet season, movement within 10 km of the conservancy was 99.9% less than movement within 5 km (Figure 6.6).

Comparisons for different sexes showed that Mabalauta's movement outside GNP changed from having smaller portions of her movement more than 5 km from the park boundary in the cold and dry season to all her movement being within 5 km in the hot and wet season. Shangana's movement outside GNP was 0.8% lower in the hot and wet season whereas his movement in the cold and dry season was all within 5 km. Therefore, in the cold and dry season Mabalauta moved further away from the boundary than Shangana did but, in the hot and wet season, the opposite is true (Figure 6.7). However, in SVC all of Patch and Tick's movement outside SVC is within 5 km of the conservancy in both seasons (

Figure 6.7).

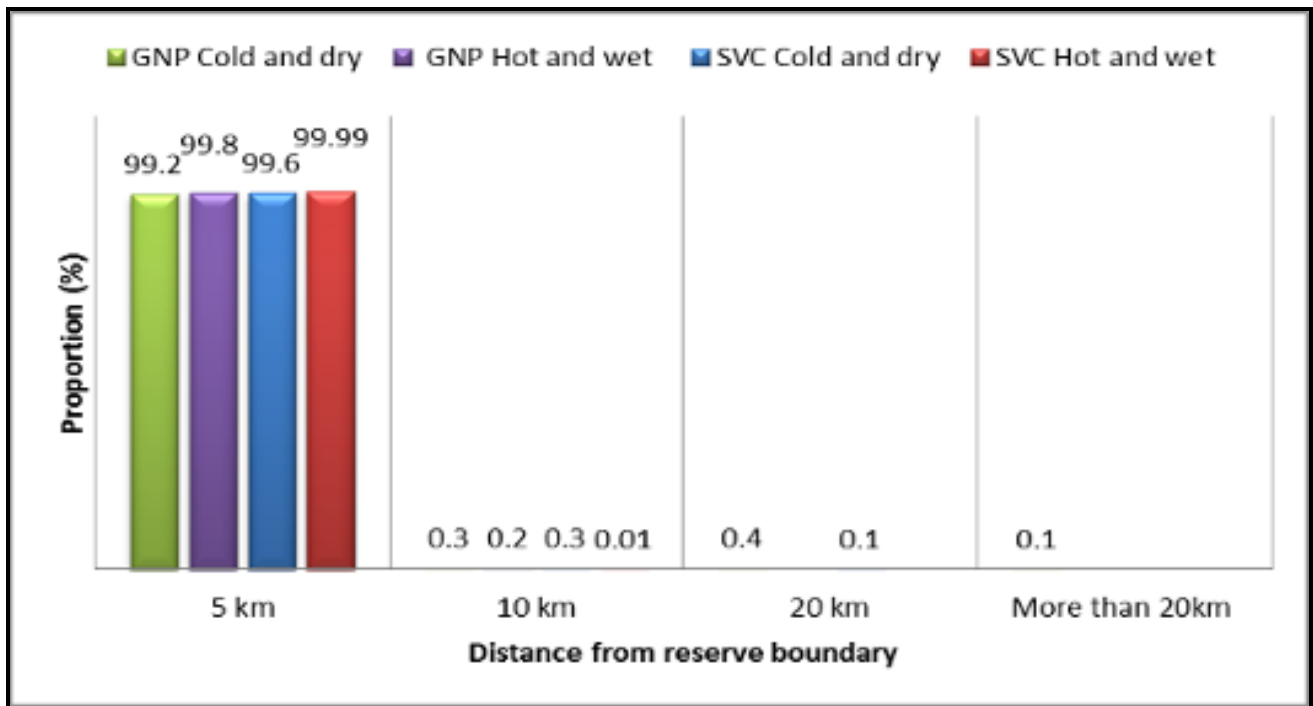


Figure 6.6 Proportions of wild dog locality points in 5 to 20 km buffer distances from GNP and SVC's boundary during the cold and dry and hot and wet seasons

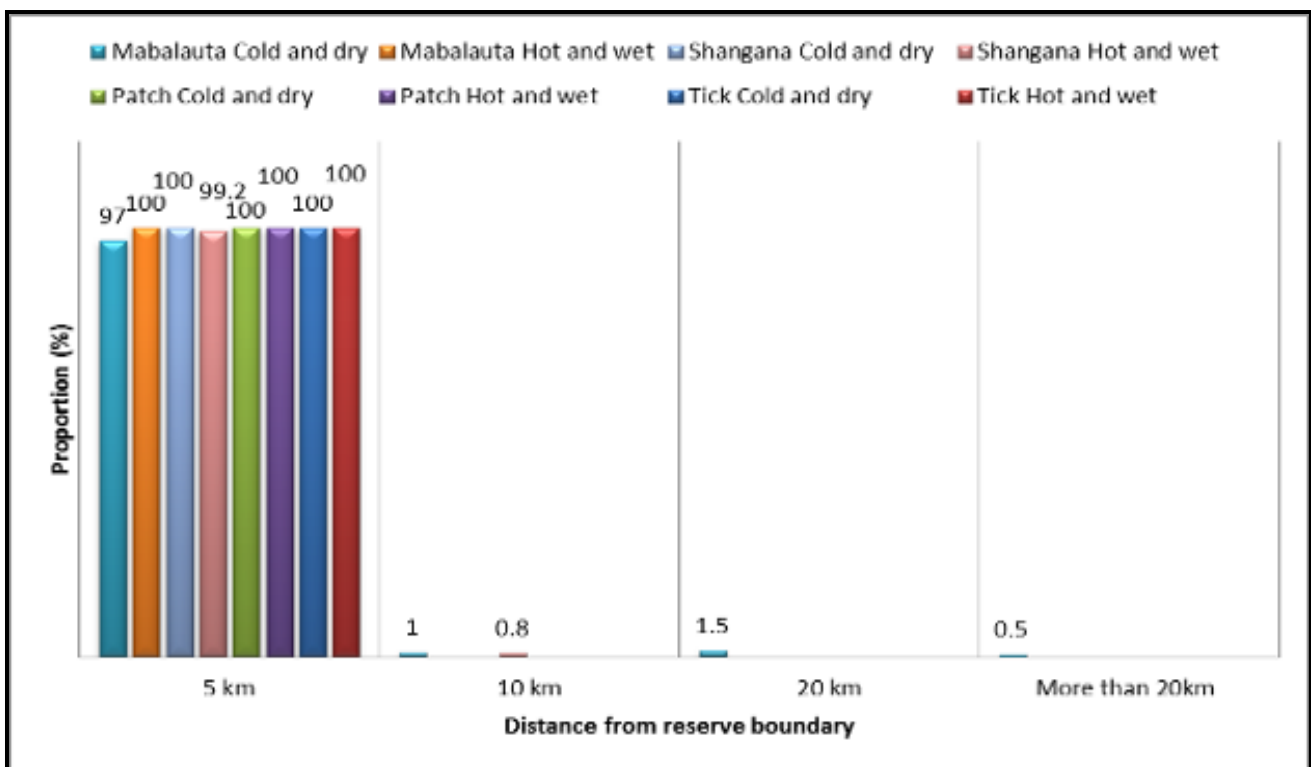


Figure 6.7 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from GNP and SVC's boundaries for the cold and dry and hot and wet seasons

Distance outside reserve boundary was assessed in the study to understand the relationship between wild dog and reserve boundaries and to understand how far wild dog move from the boundary. The results showed that wild dog perceive the boundary as a protective measure as opposed to a barrier as they did not move long distances from the boundary even though SVC's fence was stolen and GNP's fence was taken down when the GLTFCA was formed. This may confirm literature that suggests that for wild dog, the boundaries protect them from threats such as persecution (Woodroffe et al. 2007; Davies-Mostert et al. 2012) human-wildlife conflict (Goldman 2009; Gusset et al. 2009) and predation (Frantzen, Ferguson & de Villiers 2001; Swanson et al. 2014). This may additionally confirm that different species react differently to the presence of these boundaries (Hayes 2006; Newmark 2008) where whilst other species view boundaries as a restriction to their movement and flight for prey (Davies-Mostert, Mills & Macdonald 2013), larger carnivores are generally not affected (Chape et al. 2006; Karanth & De Fries 2010). In the cold and dry season, wild dog moved further outside reserves than during the hot and wet season which may be explained by den sites far away from predators (Thaker et al. 2011) or in search of prey that is not gathered at rivers where larger predators were also hunting (Darnell et al. 2014). The study also assessed whether movement from the reserve boundaries was sex specific and found that during the cold and dry season in GNP, the female moved further out of the park but during the hot and wet season, the male moved further which may have suggested sex specific movement (Herfindal et al. 2005). However, again due to the different response in SVC, no conclusions could be drawn.

6.2.2 Abiotic variables

Abiotic variables were defined as determinants of wild dog use of environmental space in the study. Five variables were assessed namely elevation, rivers, vegetation, rainfall and temperature. Unlike the biotic variables, wild dog responded to generally the same ranges of environmental variables in both GNP and SVC.

6.2.2.1 Elevation

GNP's total elevation range is between 165 and 575 m and in both seasons, more than half of wild dog movement was between 200 to 400 m. During the cold and dry season, less than a tenth of wild dog movement was in areas with less than 200 m elevation. Their movement in areas with between

200 to 400 m elevations was 50.3% and 46% lower in areas with elevation greater than 400 m. During the hot and wet season, wild dog movement in areas with less than 200 m elevation was 35.7% less than in areas with between 200 to 400 m elevations. Movement in areas with more than 400 m elevation was lower than movement in areas between 200 to 400 m, by 39.5%. Therefore, wild dog movement in areas with less than 200 m elevation was higher in the hot and wet season by 7.2% whereas movement in areas with more than 400 m was higher in the cold and dry season by 0.9% (Figure 6.8). SVC's elevation range is 480 to 620 m and majority of wild dog movement occurred between 400 to 600 m in each season. During the cold and dry season, wild dog movement in areas with more than 600 m was 73.3% lower than movement in areas between 400 to 600 m. During the hot and wet season, wild dog movement in areas with more than 600 m elevation was 79.6% lower than movement in areas with less than 600 m. This showed that wild dog movement in areas with less than 600 m elevation were higher during the hot and wet season by 3% whereas their movements in areas with elevation higher than 600 m was higher in the hot and wet season by 3.3% (Figure 6.8).

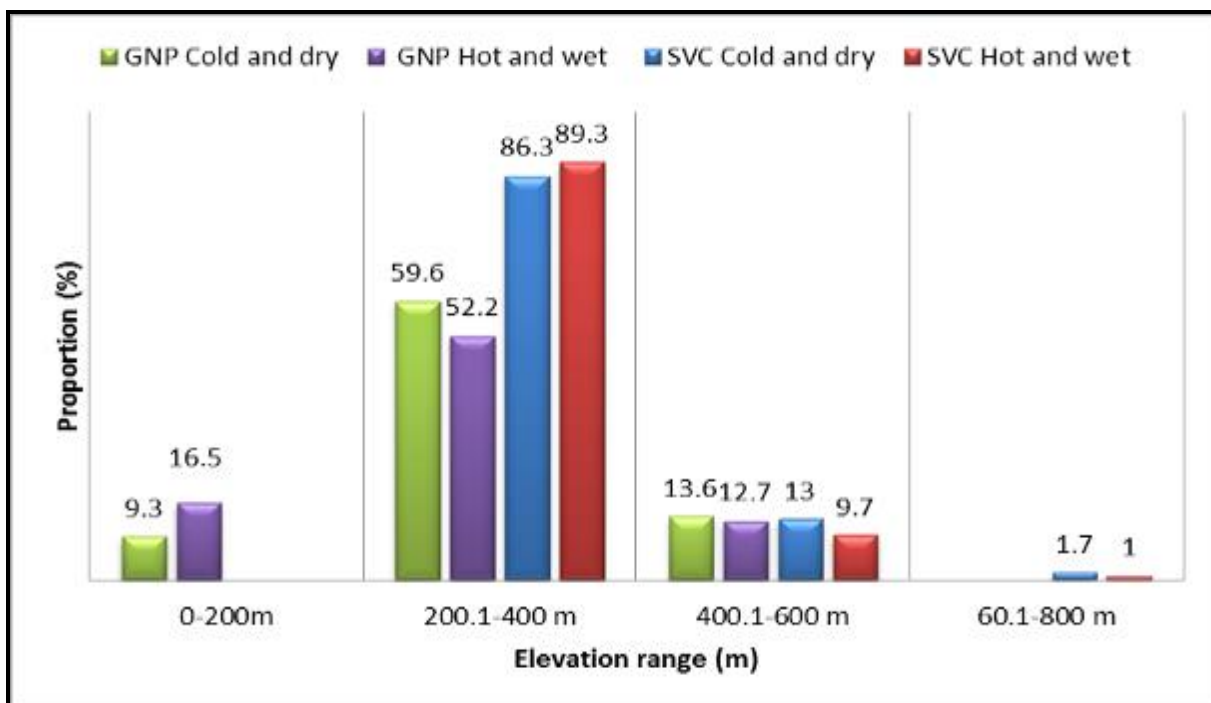


Figure 6.8 GNP and SVC proportions of wild dog locality points at different elevation ranges for the cold and dry and hot and wet seasons

Mabalauta's movement patterns had no major variations in different elevation ranges for both seasons. Her movement was higher in areas with elevation less than 400 m by 55.1% in the cold and

dry season, and by 56.3% in the hot and wet season. Shangana had most his of movement within GNP's boundary in areas with elevation less than 400 m with his movement in the hot and wet season higher by 8.6%. Therefore, Mabalauta moved in areas with between 200 to 600 m elevations more than Shangana did within GNP's boundary (Figure 6.9). In SVC, Patch's movement in areas with between 400 to 600 m was higher by 76.1% in the cold and dry season and by 71.3% in the hot and wet season, than areas with more than 600 m elevations. Tick's movement in areas with between 400 to 600 m was 5.3% lower, and in areas with more than 600 m was 5.5% higher in the hot and wet season. Patch and Tick's movement differed most in the cold and dry season where Patch's movement in areas with between 200 to 400 m elevations was less than Tick's by 4.5% but higher in areas with elevation greater than 600 m by 3.7% (Figure 6.9).

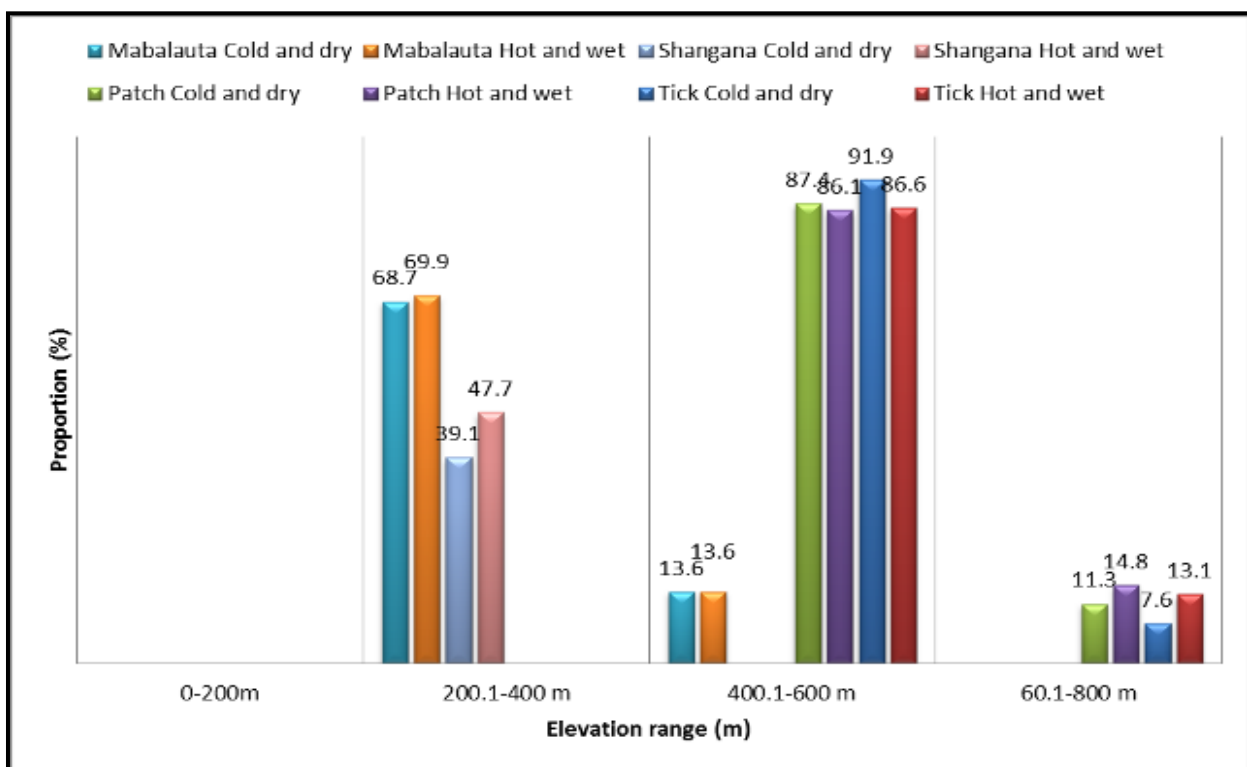


Figure 6.9 Comparison of male and female wild dog proportions in different elevation ranges for the cold and dry and hot and wet seasons in GNP and SVC

Elevation was considered in the study to test whether wild dog had a range of elevation that they preferred to move in and whether the range differed per season. The study failed to draw conclusive results, as both GNP and SVC were relatively flat areas such that wild dog had a limited range of elevation of between 200 to 800 m in which they moved in. Nonetheless, the study found that majority of wild dog movement was in areas between 200 to 600 m. This may suggest that although wild dog wide-ranging behaviour enables them to move over a varied elevation range heedless of

seasons (Rasmussen & Macdonald 2011), they prefer to centre their movement in lower elevations to facilitate easier hunting (Davies-Mostert, Mills & Macdonald 2013) as well as to avoid injuries they incur in the steeper elevations (Kratt & Kratt 2013). Based on Jackson et al. (2014)'s study, it was expected that wild dog would move in higher elevations during the cold and dry season when they denned and this was found to be true. Whilst majority of the movement in both reserves was within the median elevation values in both seasons, the cold and dry season had more movement in higher altitudes. This confirms that whilst wild dog previously denned at lower elevations (Lindsey et al. 2011) they now prefer higher elevations for den sites where they use cliffs and caves (Marsden et al. 2009) to mainly avoid predators. In addition, the study assessed movement in different elevations to determine if there would be sex specific patterns. In both GNP and SVC, the females' movements in the higher altitudes were higher than the males in both seasons. This may suggest that the females' avoidance of predators is greater than the males. However, this was inconclusive because a large portion of the male dog's movement in GNP was beyond the elevation boundary.

6.2.2.2 Rivers

In GNP, movement within 1.25 km was the highest in both the cold and dry and, hot and wet seasons. During the cold and dry season, movement within 1.25 km of the rivers was more than movement within 2.5 km by 17.6% and movement within 2.5 km was 14.2% more than movement within 5 km. In contrast, during the hot and wet season movement within 1.25 km was 39.1% more than within 2.5 km and movement within 2.5 km was 18% more than movement within 5 km. Between the two seasons, the hot and wet season had more movement within 1.25 km by 15.9% and within 2.5 km the cold and dry season had more movement by 5.6%. Movement within 5 km was higher during the cold and dry season by 9.4% and movement more than 5 km from the rivers was generally low with the highest being less than two per cent highest only during the cold and dry season (Figure 6.10). In SVC, there was not much of a difference in the wild dogs' movement and distance from the rivers in the different seasons. Within 1.25 km the hot and wet season had more movement by 0.5%, within 2.5 km the cold and dry season had more movement by 0.7% and within 5 km the cold dry seasons' movement was higher by only 0.1%. More than 5 km from the rivers, the movement also did not differ much between both seasons and was still very low (Figure 6.10).

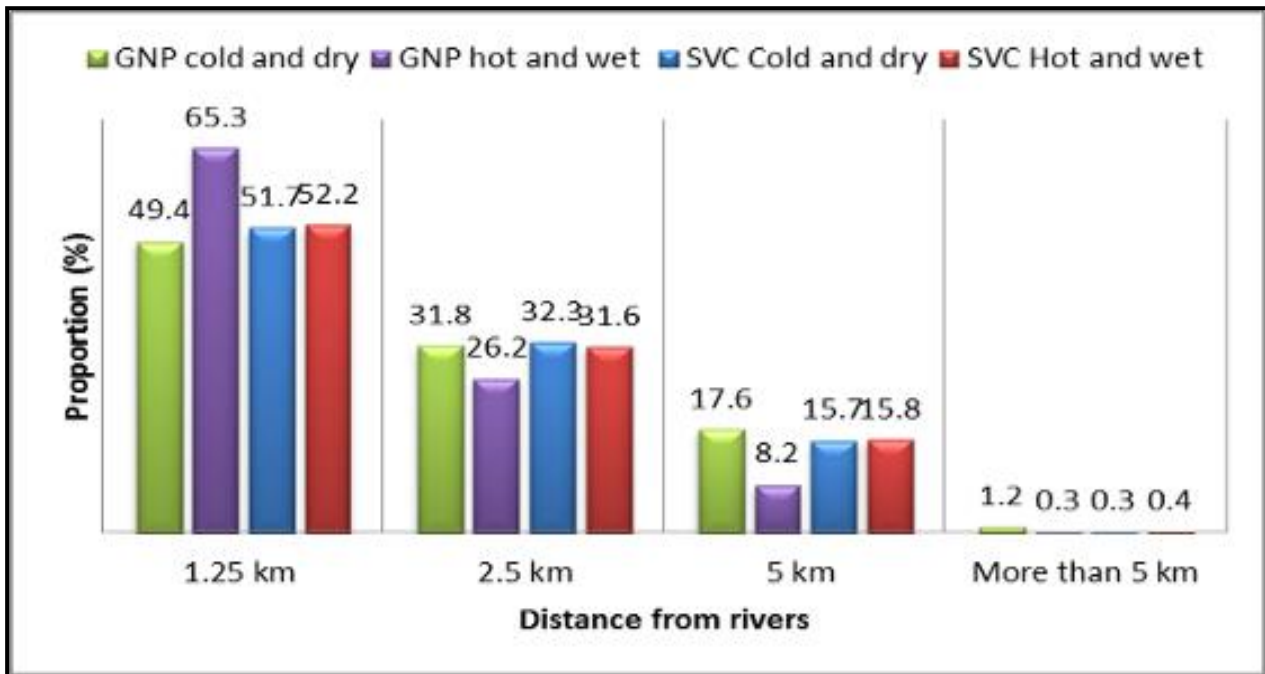


Figure 6.10 GNP and SVC proportions of wild dog locality points in 5 to 20 km buffer distances from rivers for the cold and dry and hot and wet seasons

Mabalauta had most of her movement within 1.25 km of the rivers in both seasons but the movement in the hot and wet season was higher by 15.3% and she had movement up to more than 5 km from the rivers in the cold and dry season. Shangana had most of his movement within 1.25 km during the hot and wet season, which was 30.2% higher than the cold and dry season, and very little movement more than 5 km from the rivers. During the cold and dry season, Mabalauta's movement was always higher than Shangana's except for within 2.5 km of the rivers, where Shangana's movement was 34.2% higher than hers was. During the hot and wet season, Mabalauta's movement was always lower than Shangana's and only Mabalauta had more movement more than 5 km from the rivers (

Figure 6.11). In SVC, Patch's movement during the hot and wet season was 13.1% more and 13.3% less than her cold and dry movement and her movement within 1.25 km and 5 km respectively. She had movement more than 5 km from the rivers only during the hot and wet season. Tick's movement had slight differences between the season except within 5 km where his cold and dry season movement was 4.5% more than his hot and wet season movement. He only had movement more than 5km from the rivers during the hot and wet season. Patch and Tick's movements differed slightly in both seasons except within 1.25 km Patch's hot and wet movement was about 10% more than the rest and within 5 km, her movement was 10% less (Figure 6.11).

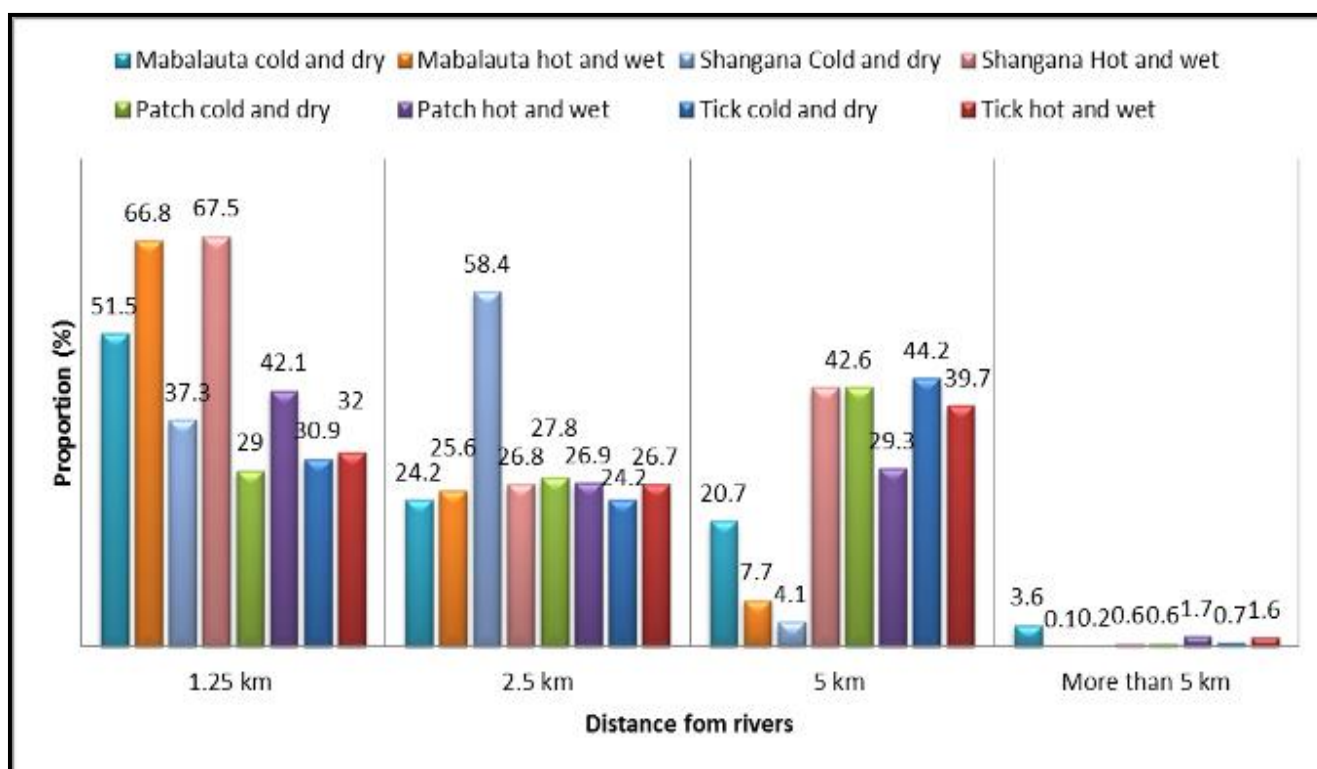


Figure 6.11 Comparison of male and female wild dog proportions in 5 to 20 km buffer distances from rivers for the cold and dry and hot and wet seasons in GNP and SVC

Rivers were assessed in the study to determine whether movement in proximity to rivers in different seasons would explain ecological processes for wild dog. The study assumed that wild dog would not maintain close proximity to rivers except in their denning seasons in order to avoid predators particularly as in GNP and SVC; wild dog have been known to move away from their home-ranges during dry seasons in order to avoid lions who favour similar prey (Groom 2014, Pers com). However, the results showed that wild dog moved close to rivers in both seasons and in GNP move further in the cold and dry season. An explanation may be that different amounts of water flow in

different seasons (Pittiglio et al. 2012). In the Savanna ecosystems where GNP and SVC are, there is less water flowing in the cold and dry season as opposed to the hot and wet season due to rainfall totals. This leads to prey clustering around permanent rivers during the cold and dry season but this also increases presence of predators and forces wild dog to spread out. However, the rivers data used in the study may have been inaccurate and out-dated leading to inaccuracies in their proximity to rivers. Their seasonal distribution around the rivers may confirm that wild dog similar to other large carnivore's also frequent rivers in reserves in search of prey that concentrate around rivers and other water bodies to get drinking water (Ford 2014). Due to their avoidance of larger predators (Webster, McNutt & McComb 2011), wild dog would probably frequent the rivers when there were fewer predators but a time for this could not be determined as the study did not consider temporal proximity to the rivers. The study also assessed whether the proximity to rivers differed for different sexes and found that whilst in GNP females moved further from the rivers than the males in the cold and dry season, in SVC there was no sex specific response to proximity to rivers. Therefore, the study also failed to finalise on whether proximity to rivers was sex specific due to the small sample sizes.

6.2.2.3 Vegetation

Majority of wild dog movement was in areas with Mopane and Terminalia/Combertrum vegetation in both seasons in GNP. During the cold and dry season, the lowest movement was in areas of cultivation and Acacia although movement in areas with Acacia 13.5% higher. Movement in areas with Terminalia/Combertrum was higher than areas with Mopane by 8.3%. In the hot and wet season, the lowest movement was also in areas of cultivation and Acacia and movement in areas with Acacia was higher by 0.7%. Movement in areas with Terminalia/Combertrum was still higher than areas with Mopane by 21%. Between the two seasons, movement in areas of cultivation did not change much but, movement in areas with Acacia was higher in the cold and dry season by 13.5% and movement in areas with Terminalia/Combertrum was 12.7% higher in the hot and wet season (Figure 6.12). Wild dog in SVC also mostly moved in areas with Mopane and Terminalia/Combretum vegetation in both seasons. Areas with Miombo vegetation had the second lowest movement in SVC for both seasons, and GNP did not have this vegetation type. During the cold and dry season, the lowest movement was in areas of cultivation by 6.9% from areas of Miombo. Movement in areas with Acacia was higher than areas of Miombo by 4.9% whilst movement in areas with Mopane was higher by 19.8% than movement in areas with

Terminalia/Combretum. In the hot and wet season, movement in areas of cultivation was slightly less than in areas of Miombo whilst movement in areas of Acacia was 15% more than in areas with Miombo. Movement in areas with Mopane was still just above movement in areas with Terminalia/Combretum. Whilst movement in areas with Acacia and cultivation was more or less the same in both seasons, movement in areas with Miombo and Mopane was 5.1% and 9.2% lower respectively in the hot and wet season and movement in areas with Terminalia/Combretum was 10.1% higher in the hot and wet season (Figure 6.12).

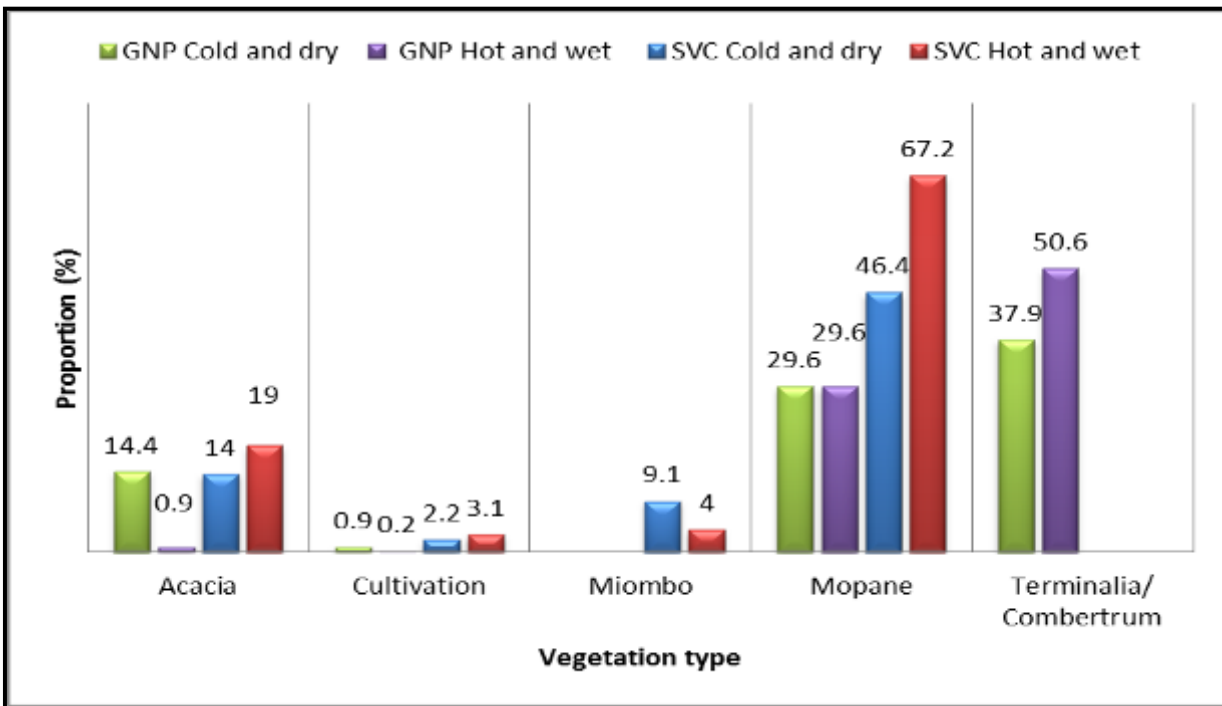


Figure 6.12 GNP and SVC proportions of wild dog locality points in different vegetation types for the cold and dry and hot and wet seasons

Mabalauta moved in areas with Acacia in the cold and dry season; her movement was 2.8% less and 0.8% in areas of cultivation and Mopane in the hot and wet season and her movement in areas with Terminalia/Combertrum was 6.3% more. Shangana's movement in areas with Mopane was 0.6% less and over Terminalia/Combertrum was 6.7% more in the hot and wet season. Mabalauta's movement in areas with Acacia, cultivation and Terminalia/Combertrum was higher by 1%, 3.2% and 41% respectively within GNP, but Shangana's movement in areas with Mopane was close to five times hers in the cold and dry season. In the hot and wet season, Shangana moved in areas with Miombo and Mabalauta's movement in areas with Terminalia/Combertrum was higher by 40.6% (Figure 6.13). Patch's movement in areas with Acacia and Terminalia/Combertrum was 0.3% more and 21.5%, and in areas of cultivation and Mopane was 3.5% and 17.4% less in the hot and wet

season. Tick avoided areas with Miombo in the hot and wet season, he had more movement in areas with Mopane by 7.2% and was 5.9% lower in areas of Terminalia/Combertrum in the hot and wet season. During the cold and dry season, Patch's movement was higher in areas of cultivation and Mopane by 3.2% and 15.6%. Tick's movement was higher in areas with Terminalia/Combertrum by 18.9% and only he moved in areas with Acacia and Miombo. In the hot and wet season, Tick's movement in areas with Mopane was higher by 9% and hers in areas with Terminalia/Combertrum was higher by 8.5% (Figure 6.13).

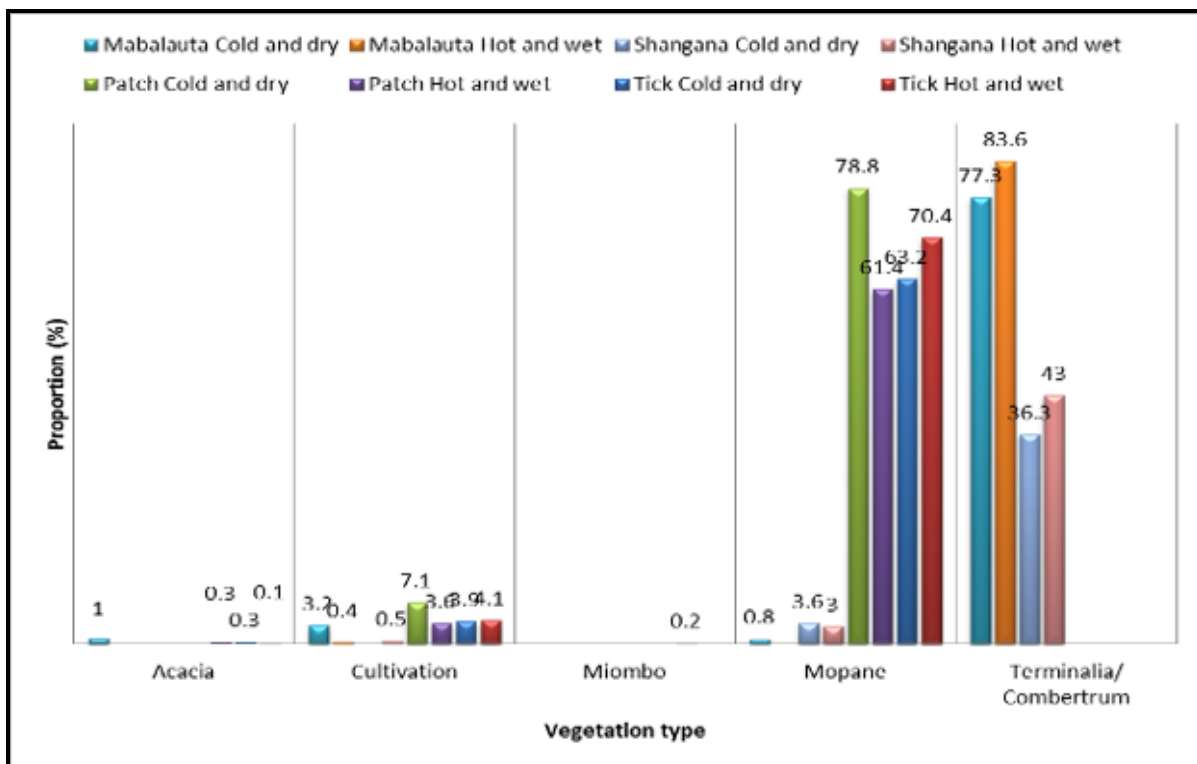


Figure 6.13 Comparison of male and female wild dog proportions in different vegetation types for the cold and dry and hot and wet seasons in both GNP and SVC

Different vegetation types were present in GNP and SVC. Acacia, Miombo, and Mopane are tree species that are less dense in the cold and dry season when they shed their leaves as opposed to the hot and wet season when they become dense with full canopies (Gandiwa & Kativu 2009). Cultivated land is less dense in the cold and dry season when it is being harvested compared to the hot and wet season when it is being ploughed. Terminalia/Combretum is grassland whose density is generally consistent throughout seasons, but can be altered by grazing (Tafangenyasha 1997). Vegetation type was used in the study as a surrogate for vegetation density to assess whether wild

dog movement avoided thicker dense vegetation whilst hunting, or even preferred it during denning seasons.

The results showed that generally wild dog preferred to move in areas that had grasslands in both seasons and in areas with the tree species in the cold and dry season when they had shed their leaves. This can be explained by the findings of Bauer (2003) that wild dog find it easier to hunt due to better vision and easier movement in grasslands; and confirms Buettner et al. (2007)'s study that found that wild dog prefer to hunt in sparse vegetation because lower grass, smaller shrubs and less greenery mean weaker prey. Their movement in the grasslands was higher in the wet seasons when trees had full canopies. This can further be explained by how wild dog hunt by sight and mostly at dawn and dusk (Kratt & Kratt 2013) but, are colour blind such that it is difficult for them to identify stationary prey camouflaged in vegetation (Burrows 2011) and it is easier to avoid predators in sparse vegetation (Whittington-Jones, Parker & Davies-Mostert 2011). However, the results were inconclusive firstly because vegetation type was used instead of density and secondly because Terminalia/Combretum and Mopane were the main vegetation types in the study areas and wild dog may move differently in other vegetation types. The study also considered the influence of vegetation on different sexes but the study failed to find any major differences in wild dog movement in different vegetation types in both seasons.

6.2.2.4 Rainfall

GNP's rainfall range is between 10 to 17 mm in the cold and dry season and between 77 to 105 mm in the hot and wet season. In the cold and dry season, 81.4% of wild dog movement was in areas that received 11 to 14 mm rainfall whilst 0.7% was in areas that received less than 11 and more than 14 mm. The highest movement was in areas that received 11 mm and the lowest was in areas that received 10 mm. During the hot and wet season, 70.7% of wild dog moved in areas that received between 80 and 100 mm whilst less than a tenth were in areas that received less than 80 mm and close to 2% were in areas receiving more than 100 mm (Figure 6.14).

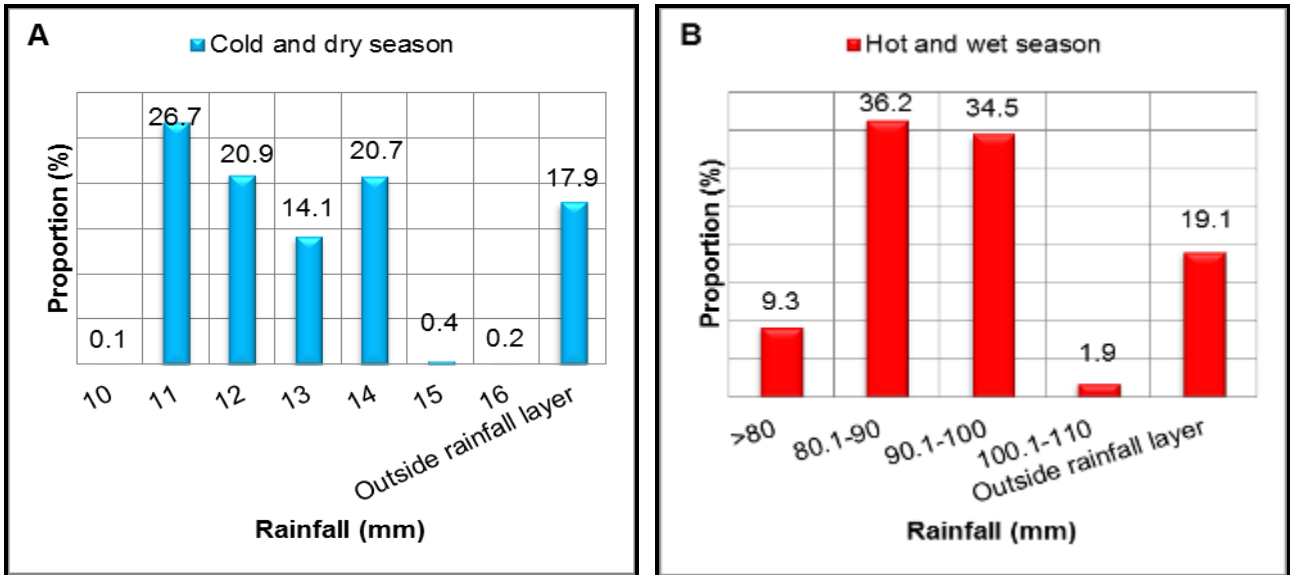


Figure 6.14 GNP proportions of wild dog locality points at different rainfall ranges for the cold and dry (blue) and hot and wet (red) seasons

In SVC precipitation ranges from eight to 15 mm in the cold and dry season and from 75 to 110 mm in the hot and wet season. During the cold and dry season, 86.3% of the movement was in areas that received between 9 to 10 mm whereas 11.6% was in areas that received 11 to 13 mm and less than 2% was in areas that received eight mm. During the hot and wet season, close to two thirds of the movement was in areas that received between 80 and 90 mm with areas receiving less than 80 mm having 42.2% less movement and those receiving more than 90 mm having 46.3% less movement. The least movement in the hot and wet season was in areas that received more than 100 mm (Figure 6.15)

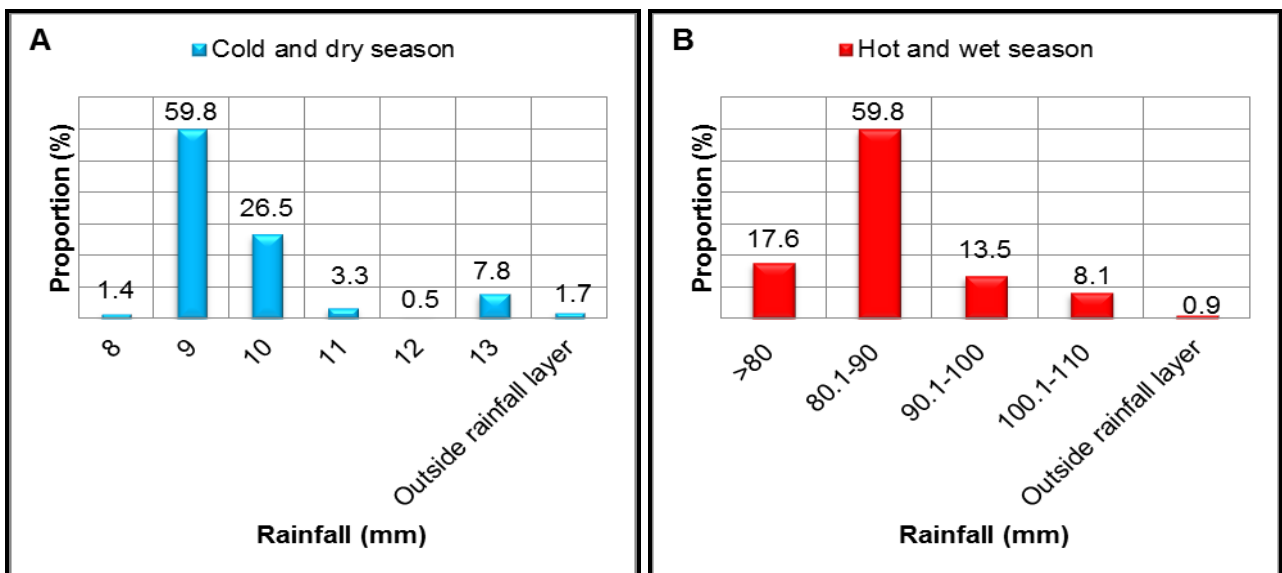


Figure 6.15 SVC proportions of wild dog locality points at different rainfall ranges for the cold and dry (blue) and hot and wet (red) seasons

During the cold and dry season, 62.8% of Mabalauta's movement was found in areas that received 12 to 13 mm rainfall and 32.1% of Shangana's movement was in areas that received 11 to 12 mm rainfall. In area with the lowest rainfall (10 mm), only Shangana had movement whereas in areas with rainfall higher than 13 mm only Mabalauta had movement within GNP. During the hot and wet season, both Mabalauta and Shangana had most of their movement in areas that received between 80 and 90 mm of rainfall. Mabalauta had twice Shangana's movement in areas that received less than 80 mm and, she had more movement in areas that received more than 90 mm. However, comparing their movement was difficult, as the rainfall in areas of close to two thirds of Shangana's movement could not be assessed in the cold and dry season and just below half in the hot and wet season (Table 6.1). Both Patch and Tick had most of their movement in areas that received nine mm rainfall in the cold and dry season. In areas that received eight mm, Patch's movement was greater than Ticks by 4.47% and Tick's movement was greater than Patch's by 4.1% in areas that received 10 mm. During the hot and wet season, both Patch and Tick also mostly moved in areas that received between 80 to 90 mm rainfalls. Patch's movement in areas that received less than 80 mm was less than Tick's by 3.6% and Tick's was less than Patch's in areas that received more than 90 mm by 0.1% (Table 6.1).

Table 6.1 Comparison of male and female wild dog proportions in different rainfall ranges for the cold and dry and hot and wet season in GNP and SVC

		Proportion of movement (%)			
Cold and dry season		Mabalauta	Shangana	Patch	Tick
Rainfall (mm) value	08	--	--	11.1	6.6
	09	--	--	86.7	87.3
	10	--	0.8	0.8	4.9
	11	12.0	18.1	--	0.9
	12	40.6	14.0	--	--
	13	22.2	4.7	--	--
	14	6.1	--	--	--
	15	1.3	--	--	--
	16	0.6	--	--	--
Wild dog points outside rainfall layer boundary		17.2	62.4	2.4	1.3
Hot and wet season					
Rainfall (mm) values	77 -80	26.3	12.7	29.7	33.3

80.1-90	40.6	44.5	69.4	66.5
90.1-100	10.6	--	0.2	0.1
100.1-110	3.1	--	--	--
Wild dog points outside rainfall layer boundary	19.4	42.8	0.7	1.1

Rainfall was assessed in the study to understand if wild dog had specific responses to areas that received different rainfall. Based on the study's results, wild dog mostly move in areas receiving nine to thirteen mm rainfall in the cold and dry season, and areas receiving 80 to 90 mm during the hot and wet season although the rainfall range is as high as 110 mm. The movement in the cold and dry season confirms that wild dog favour low rainfall in denning seasons because there is less likely chances of flooding (Becker et al. 2012; Woodroffe & Sillero-Zubiri 2012). This finding may also complement Buettner et al. (2007)'s findings that wild dog prefer low rainfall totals because sparse vegetation makes prey easier to catch and increases the likelihood of the denning season being successful. In the hot and wet season, wild dog use mostly areas that are receiving 80 to 90 mm rainfall. This suggests that although rainfall's influence on wild dog is not major, they do prefer areas with lower rainfall. The study used rainfall data that had a temporal difference of 14 years due to a lack of data such that these results may not be an accurate representation of wild dog relationship to rainfall. In addition, the study also assessed whether there were relationships based on different sexes for wild dog and rainfall. Similar to vegetation, there were no major differences between the female and male's movements to suggest a sex specific relationship.

6.2.2.5 Temperature

In GNP, temperature ranged between 20° to 23°C during the cold and dry season, and between 26° to 29°C during the hot and wet season. Most of wild dog movement was in areas with between 21.1° and 22°C temperature during the cold and dry season. Movement in areas that had temperatures less than 21°C was less than movement in areas with 21.1° to 22°C, by 43.3%. In addition, movement in areas with more than 22°C temperature was less than movement in areas between 21.1° to 22°C, by 60.6%. During the hot and wet season, movement in areas with between 27.1° and 28°C had the highest proportion of movement. Movement in areas that had temperatures less than 27°C was two times less than movement in areas with 27.1° to 28°C and movement in areas with more than 28°C was very minor (Figure 6.16).

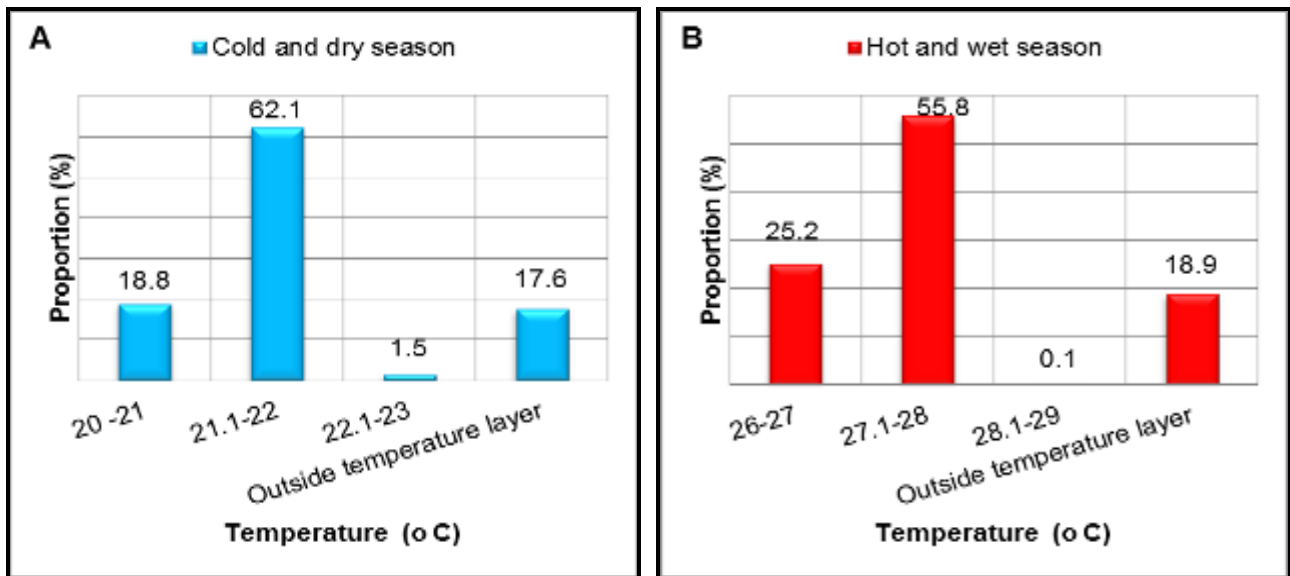


Figure 6.16 GNP proportions of wild dog locality points at different temperature ranges for the cold and dry (blue) and hot and wet (red) season

SVCs temperatures ranged between 18° and 21°C during the cold and dry season and between 23° and 26°C during the hot and wet season. During the cold and dry season, highest movement was in areas that had between 20.1° to 21°C temperature. Less than a tenth of the movement was in areas with less than 19°C temperature and movement in areas that had between 19.1° and 20° C was 16.8% more than areas with less than 19°C and 37.5% less than areas with more than 20°C. In the hot and wet season, the movement in areas with between 24.1° and 25°C and those with 25.1° and 26°C differed by 1.1%. The lowest movement was in areas with less than 24°C by 18.3% (Figure 6.17).

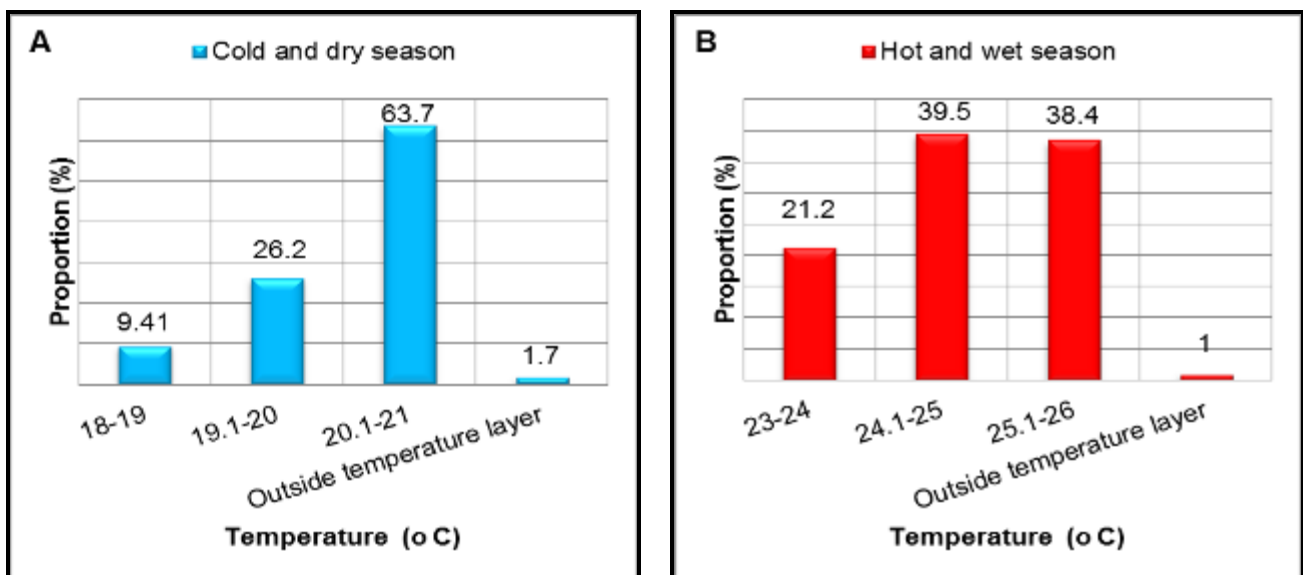


Figure 6.17 SVC proportions of wild dog locality points at different temperature ranges for the cold and dry (blue) and hot and wet (red) seasons

During the cold and dry season, less than a tenth of Mabalauta's movement was in areas that had a temperature less than 20°C and Shangana's movement in areas that had more than 22°C was lower. In areas that had 21.1° to 22°C Shangana's movement was higher and in areas that had more than 22°C Mabalauta's movement was higher by 6.9%. In the hot and wet season, almost half of Mabalauta's movement was in areas that had 27.1° to 28°C whereas Shangana's movement in areas with between 27.1° to 28°C was 20% lower. Mabalauta's movement in areas with between 27.1° to 28°C was higher by 33.6% and his movement in areas with more than 28°C was higher by 16.3% (Table 6.2). In SVC, Patch's movement in areas with less than 19°C was 45.5% lower and Tick's movement was 26.4% lower in areas that had more than 20°C. In areas that had between 19.1° to 20°C, Tick's movement was higher by 15.8% and in areas that had more than 20°C, Patch's movement was higher by 11.8%. In the hot and wet season, Patch's movement was 9.9% lower in areas that had less than 24°C and by 25.3% in areas that had more than 25°C. Tick's movement was also 14.5% lower in areas that had less than 24°C and 24.5% lower in areas that had more than 25°C. Patch's movement was higher by 2.7% in areas that had less than 24°C but Tick's movement was higher in areas between 24.1° and 25°C and more than 25°C by 1.9% and 2.7% respectively (Table 6.2).

Table 6.2 Comparison of male and female wild dog proportions in different temperature ranges for the cold and dry and hot and wet season in GNP and SVC

		Proportion of movement (%)			
Cold and dry season		Mabalauta	Shangana	Patch	Tick
Temperature (°C)	18-19	--	--	1.9	--
	19.1-20	9.3	--	47.4	63.2
	20.1-21	71.8	--	48.6	36.8
	21.1-22	6.0	32.6	--	--
	22.1-23	12.9	6.0	--	--
Wild dog points outside temperature layer			38.6	2.1	1.0
Hot and wet season		--			
Temperature (°C)	23-24	--	--	34.4	31.7
	24.1-25	0.2	--	44.3	46.2
	25.1-26	16.2	--	19.0	21.7
	26.1-27	21.3	--	--	--
	27.1-28	47.1	13.5	--	--

28.1-29	17.2	33.5	--	--
Wild dog points outside temperature layer	--	53.0	2.3	0.4

Temperature was assessed to identify whether there were specific movement patterns in particular temperature ranges. Temperature does not directly affect wild dog due to their thermoregulation mechanisms (Groom 2014, Pers com), but temperature does affect their prey. The study results showed that presumably the ideal temperature range for wild dog in the cold and dry season is 19° to 21°C whilst in the hot and wet season the range is between 24° to 28°C. There was a very small degree of variation between the two seasons, which suggests that either wild dog prefer medium temperatures or that they are forced to contend with the small range, which is characteristic of Savanna climates. Seeing as both GNP and SVC have cold and dry seasons, wild dog preference of medium temperature may be an indication of their preferred environmental space having suitable conditions for successful denning seasons. Wild dog were expected to prefer higher temperatures, which would lead the prey to tire more rapidly during chase (Woodroffe et al. 2005). However, wild dogs usually hunt at dusk and dawn (Burrows 2011) when temperatures are generally lower. The study also assessed temperature ranges for different sexes, but did not find major differences in the movement patterns for males and females in the temperature ranges wild dog moved. This suggests that there is no sex specific relationship between wild dog movement and temperature ranges.

6.2.3 Relationship between variables

In practice, correlation values higher than 50% show that variables are autocorrelated and will lead to statistically incorrect results (Field 2007). In the study, the results for Pearson's correlation run on the variables are presented using pivot tables where the point count was wild dog localities and grey highlights show variables with high correlations. Pearson's correlation method on the biotic variables showed that there was no correlation greater than 0.5 (Table 6.3). Field (2007) explained that the rule-of-thumb is that auto correlation values greater than 0.5 will lead to statistically incorrect results. In GNP, the highest correlation was between the reserve boundary and the roads whilst in SVC, the highest correlation was between roads and human influences. However, both these values were below the 0.5 rule-of-thumb.

Table 6.3 Correlation between biotic variables in the cold and dry season in both GNP (A) and SVC (B)

A		Human Influences	Roads	Reserve boundary	B		Human Influences	Roads	Reserve boundary
GNP	Human Influences	1	-.101**	-.059**	SVC	Human Influences	1	-.121**	-.005
	Roads	-.101**	1	.154**		Roads	-.121**	1	.090**
	Reserve boundary	-.059**	.154**	1		Reserve boundary	-.005	.090**	1

Pearson's correlation method on the abiotic variables was run twice on the cold and dry, and hot and wet season because of the different rainfall and temperature values. The abiotic variables had mostly high autocorrelation values greater than 0.5 shown in Tables 6.4 and 6.5, the variables not autocorrelated are shown in grey in the tables. In GNP, all correlations were higher than 0.9 except between rivers and elevation, and rivers and temperature in the cold and dry season (Table 6.4A). Similarly, in SVC, all correlations were higher than 0.5 except between the same variables (Table 6.4B).

Table 6.4 Correlation between abiotic variables in the cold and dry season in both GNP (A) and SVC (B)

A		Elevation	Rivers	Rainfall	Temp	B		Elevation	Rivers	Rainfall	Temp
GNP	Elevation	1	-.104**	.926**	.946**	SVC	Elevation	1	-.169**	.551**	.775**
	Rivers	-.104**	1	-.100**	-.103**		Rivers	-.169**	1	-.526**	-.170**
	Rainfall	.926**	-.100**	1	.965**		Rainfall	.551**	-.526**	1	.726**
	Temp	.946**	-.103**	.965**	1		Temp	.775**	-.170**	.726**	1

During the hot and wet season, rivers and temperature were also autocorrelated in GNP (Table 6.5A) and SVC (Table 6.5B). Therefore, rainfall, temperature, and elevation were autocorrelated meaning their influence in modelling wild dogs' movement and distribution would be similar and redundant.

Table 6.5 Correlation between abiotic variables in the hot and wet season in both GNP (A) and SVC (B)

A		Elevation	Rivers	Rainfall	Temp	B		Elevation	Rivers	Rainfall	Temp
GNP	Elevation	1	-.094**	.966**	.986**	SVC	Elevation	1	-.163**	.505**	.984**
	Rivers	-.094**	1	-.993**	-.112**		Rivers	-.163**	1	-.794**	-.076**
	Rainfall	.966**	-.993**	1	.945**		Rainfall	.505**	-.794**	1	.831**
	Temp	.986**	-.112**	.945**	1		Temp	.984**	-.076**	.831**	1

In GNP, elevation, temperature, and rainfall had the highest correlation with values more than 90% whilst roads and rivers had the second highest correlation close to 60%. Between the highly autocorrelated variables, the variables with more influence in the model have stronger relationships with the dependent variable (Field 2007). Therefore, in GNP rivers explained wild dog distribution

better than the roads by 3.16% and elevation explained wild dog distribution better than the rainfall and temperature by 20.5% and 57% respectively (Table 6.6).

Table 6.6 Variables autocorrelations calculation in SPSS for GNP using two tailed Pearson's correlation

	Correlations							
	Point Count	Human settlements	Roads	Reserve Boundary	Elevation	Rivers	Rainfall	Temperature
Point Count	1	.447**	-.205**	-.074**	.304**	-.111**	.099**	-.279**
Human settlements	.447**	1	.085**	.181**	-.030	-.430**	-.374**	.137**
Roads	-.205**	.085**	1	.165**	.122**	-.597**	.115**	-.079**
Reserve Boundary	-.074**	.181**	.165**	1	-.050	-.154**	-.135**	.110**
Elevation	.304**	-.030	.122**	-.050	1	-.339**	.909**	-.964**
Rivers	-.111**	-.430**	-.597**	-.154**	-.339**	1	-.109**	.230**
Rainfall	.099**	-.374**	.115**	-.135**	.909**	-.109**	1	-.939**
Temperature	-.279**	.137**	-.079**	.110**	-.964**	.230**	-.939**	1
**. Correlation is significant at the 0.01 level (2-tailed).								

In SVC, elevation, temperature, and rainfall also had the highest correlation with values averaging more than 81.2% whilst roads and rivers were autocorrelated (Table 6.7). Between the correlated variables, rivers and elevation had more influence in determining wild dog distribution. In SVC, the rivers explained wild dog distribution better by 8.8% whereas elevation explained the distribution better than rainfall by 8.2% and temperature by 10%.

Table 6.7 Variables autocorrelations calculation in SPSS for SVC using two tailed Pearson's correlation

	Correlations							
	Point Count	Human settlements	Roads	Reserve Boundary	Elevation	Rivers	Rainfall	Temperature
Point Count	1	-.131**	.354**	-.084**	-.177**	.442**	-.089**	.071**
Human settlements	-.131**	1	.280**	.171**	.044**	.015	-.270**	.218**
Roads	.354**	.280**	1	.135**	-.033*	.770**	-.087**	.014
Reserve Boundary	-.084**	.171**	.135**	1	-.032	-.124**	-.124**	.092**
Elevation	-.177**	.044**	-.033*	-.032	1	-.324**	.703**	-.901**
Rivers	.442**	.015	.770**	-.124**	-.324**	1	-.148**	.218**
Rainfall	-.089**	-.270**	-.087**	-.124**	.703**	-.148**	1	-.831**
Temperature	.071**	.218**	.014	.092**	-.901**	.218**	-.831**	1
**. Correlation is significant at the 0.01 level (2-tailed).								

Correlation between biotic and abiotic variables used in the study were measured to outline which variables were important for wild dog and to assess whether running a model with all the variables would explain wild dog distribution. Pre-modelling check for autocorrelation above, selected human settlements, rivers, reserve boundaries, elevation, and vegetation for modelling. The results show each variable without the autocorrelated ones, had a different influence on the models in both GNP and SVC, which confirmed that different variables influence the distribution pattern of wild dog (Woodroffe et al. 2007). In the study, linear features had high correlations, which may have been due to the roads, and rivers in Zimbabwe historically placed close together to allow easier agriculture (Gandiwa et al. 2011). Correlations between elevation, rainfall, and temperature confirmed Bucklin et al. (2014)'s study which found that in models, climatic variables consistently have higher values in SDM due to their spatial correlation, but do not always reflect their true relationship to a species. In addition, the correlation between temperature and rainfall may have been because WorldClim data was an average over ten years with a coarse resolution and not daily data values that coincided with the species data. Therefore, the importance of carefully considering the choice of explanatory variables in SDM (Caryl et al. 2014) is necessary because variables have an unpredictable impact on the accuracy of models over a range of sample sizes (Stockwell & Peterson 2002).

6.2.4 Variables contribution to models' output

MaxEnt used responses curves and jackknife tests to assess each variable's effect on the probability distribution, whilst BIOMOD used variable importance on each of the models outputs. Both MaxEnt and BIOMOD used the model's training gain to measure variable importance to estimate the permutation importance of each variable in the resulting models for GNP and SVC. Response curves and jackknife tests for the reserves are discussed below, whilst results for packs can be found in Appendix E and F respectively.

6.2.4.1 Variable effect on prediction

MaxEnt's variable response curves show the variation in prediction of the model as a variable either increases or decreases and secondly, how the model's prediction is based on variable's individual and cumulative contributions to the model (Phillips & Dudík 2008). In both GNP (Figure 6.18), and SVC (Figure 6.19) wild dog movement increased with distance from the human settlements. Although the response in GNP decreased in 20 to 30 km, in SVC the movement continuously increased with distance from the human settlements. Whilst the pattern in SVC was expected, the decrease in the movement from the human settlements in GNP was odd and was explained by Machaniwa, Mabalauta, and Shangana (Appendix E) occasionally moving close to the human settlements. Other packs as well as predators may have influenced the response curves in both reserves. In both parks, movement decreased with distance from the reserve boundary and were high in the same vegetation types (Mopane and Terminalia/Combretum).

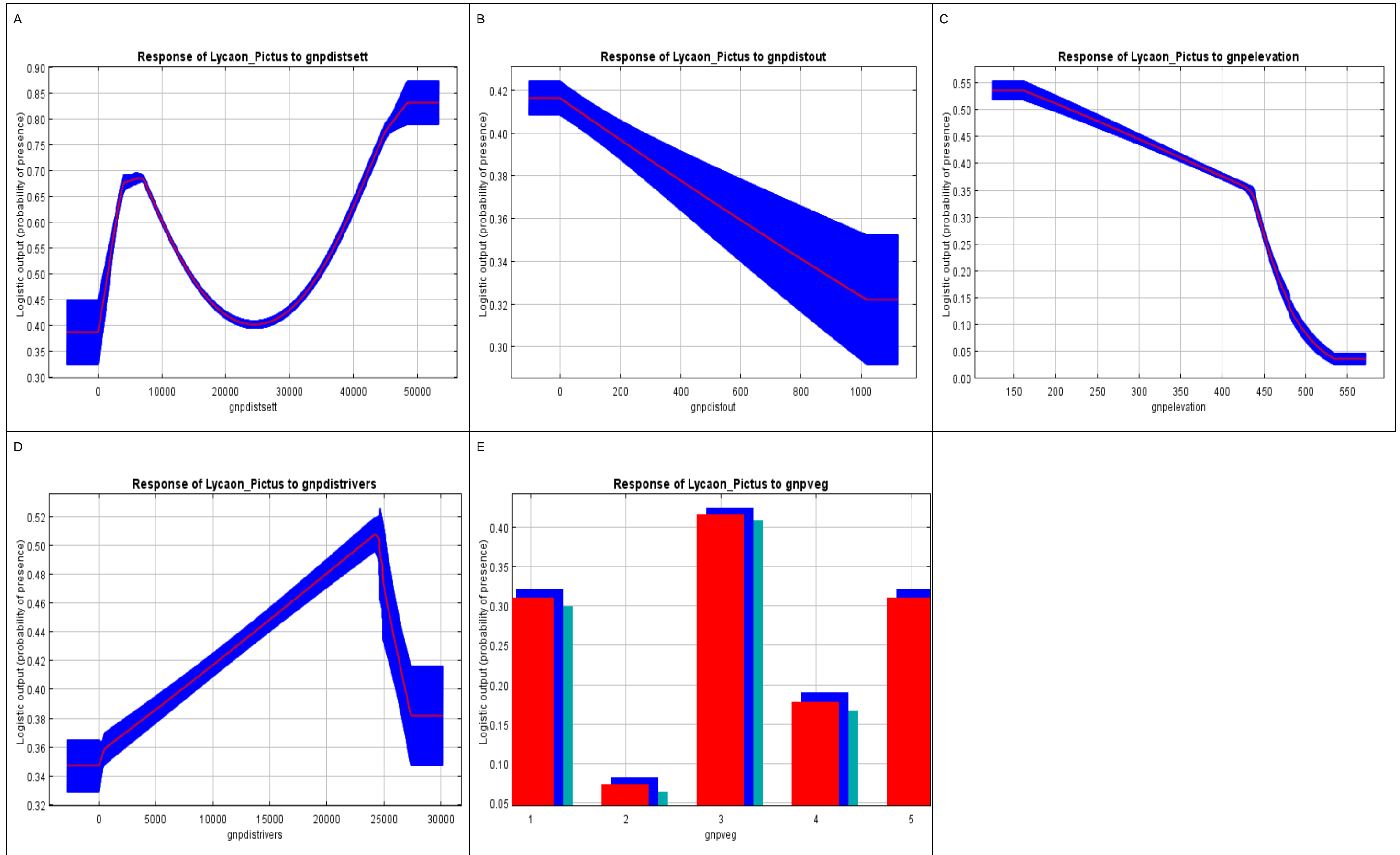


Figure 6.18 Response curves for the variables effect on predictions in GNP plotted as logistic prediction on the y-axis against its weight in the model on the x-axis for two biotic variables (a) Distance to human influences, and (b) Distance to reserve boundary, and three environmental variables (c) elevation, (d) Distance to rivers, and (e) vegetation

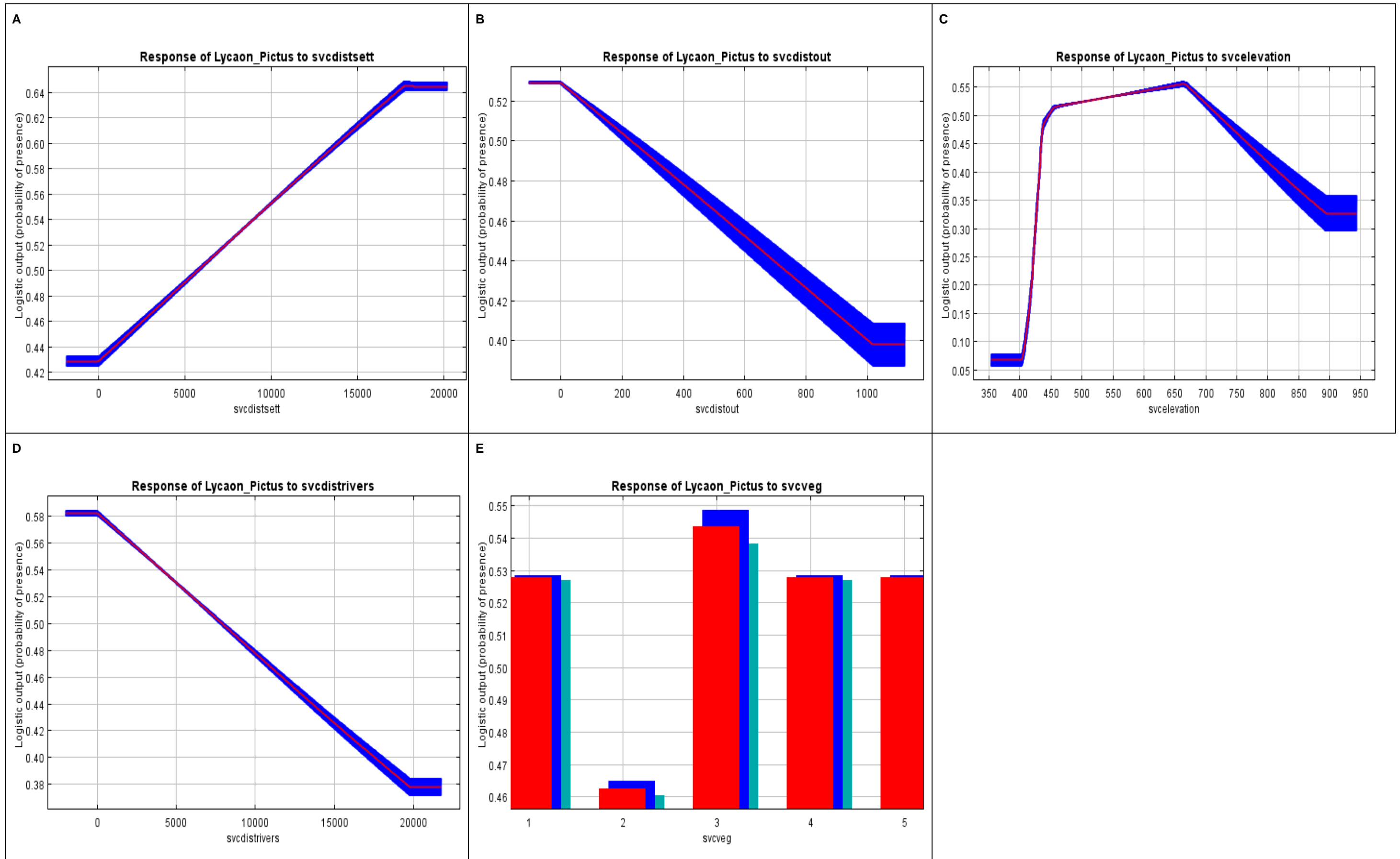


Figure 6.19 Response curves for the variables effect on predictions in SVC plotted as logistic prediction on the y-axis against its weight in the model on the x-axis for two biotic variables (a) Distance to human influences, and (b) Distance to reserve boundary, and three environmental variables (c) elevation, (d) Distance to rivers, and (e) vegetation

Jackknife tests for both reserves (Figure 6.20) showed that the variables had different influence in the output models for each of the reserves. In GNP, distance outside the reserve boundary was of no importance as an independent variable but had the highest per cent loss when the model was run without it. Vegetation was the most influential variable in the model but had almost the same influence on the model as human settlements did. In SVC, the same trend was seen for the distance from reserve boundary; however, the least important variable was vegetation. In SVC, settlements, rivers and elevation had almost the same influence on the model, but rivers had higher gain whilst elevation had higher loss.

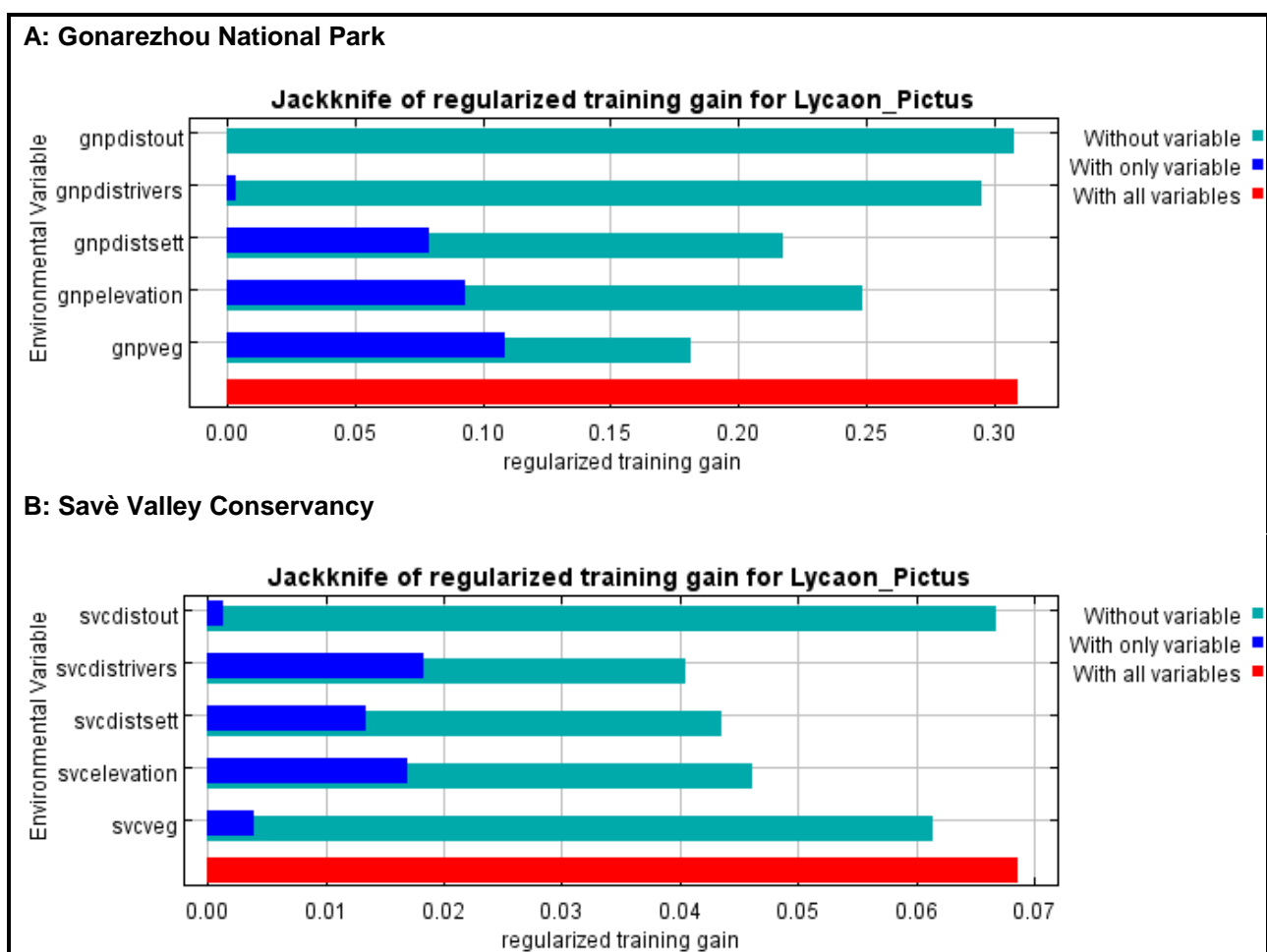


Figure 6.20 Jackknife tests for the variables effect on predictions in GNP (A) and SVC (B)

6.2.4.2 Variable permutation importance within the reserves

The most important variable within both reserves was the distance from human settlements that contributed more than a third to the model's probability distributions. The least important variable

was the distance from the reserve boundary that contributed an insignificant proportion to the model (Table 6.8). In GNP, the second most important variable was vegetation whereas the second most important variable in SVC was distance to rivers. ROC AUC values for both reserves were higher than 0.5 showing that the probability distributions identified for the wild dogs had relatively high accuracy.

Table 6.8 MaxEnt model analysis of each variables contribution to wild dog prediction models in GNP and SVC

Reserve	ROC AUC	Variables contribution calculated as increase in regularized gain				
		Human settlement	Rivers	Reserve Boundary	Elevation	Vegetation
Gonarezhou National Park	0.75	35.0	06.8	0.3	27.5	30.4
Savè Valley Conservancy	0.62	34.2	30.1	2.0	22.5	11.2

To assess the accuracy and robustness of the variable importance order output by MaxEnt GUI, variable importance was also assessed in BIOMOD using GAM, GLM, and MaxEnt within the parks. The order of variable importance was similar to the MaxEnt GUI output where the most important variable was distance to human settlements in both reserves and the least important variable was the distance outside the reserve boundary (Table 6.9).

Table 6.9 BIOMOD variables importance in the GLM, GAM, and MaxEnt models for GNP and SVC

	Model	ROC AUC	Variables contribution calculated as increase in regularized gain				
			Human settlement	Rivers	Reserve Boundary	Elevation	Vegetation
Gonarezhou National Park	GAM	0.75	49.3	9.8	1.0	17.3	22.6
	GLM	0.69	41.7	13.2	0.0	18.6	26.5
	MaxEnt	0.77	47.3	3.8	0.1	14.2	34.6
Savè Valley Conservancy	GAM	0.69	50.3	21.8	0.9	16.7	10.3
	GLM	0.65	38.0	31.2	0.1	21.6	9.1
	MaxEnt	0.70	39.5	35.7	1.0	13.8	10.0

Variable importance was assessed in the study to both understand how wild dogs were affected by the variables and to assess the accuracy of the model's output. The results showed ROC AUC values for all models in GNP were higher than in SVC because MaxEnt is optimised for small data sets and SVC had a larger number of samples (Seo et al. 2009; Edren et al. 2010). Therefore, this confirmed that the ROC AUC is informative when there are true cases of absence available (Jiménez-Valverde 2012) so that it can be verified. Distance from human settlements was the most important variable whilst distance from the reserve boundary was the least influential variable

inside the reserves complemented Bucklin et al. (2014)'s findings that models created using human settlements produce significantly more accurate models. However, wild dogs were secondarily affected by vegetation in GNP and by distance from rivers in SVC. These differences suggest that whilst similar variables affect wild dog, the effect is not uniform. This may be due to differences in location and sizes of UDs, which affects prey, predation by larger carnivores and the degree of human-wild dog conflict that they experience. The results also showed that whilst SDM explain variable importance differently, there are similarities in the variable importance in the output model. This reinforced that consensus models (use both biotic and abiotic data) that are based on an average function algorithm may increase significantly the accuracy of species distribution forecasts (Marmion et al. 2009).

MaxEnt produced probability distributions for wild dog in GNP and SVC. GNP and SVC's models had ROC AUC values of 0.75 and 0.62 respectively. GNP and SVC's ROC AUC values were lower than those run on the packs separately which the study revealed was in response to the increase in sample size (that is from one pack, to all collared wild dog in a reserve). Total output value was calculated using wild dog constraints and entropy to map their probability with a blue-to-red symbology. Areas with values close to zero (blue) had the least probability of wild dog occurrence whilst areas with values closer to one (red) the highest probability of wild dog occurrence. In both reserves, higher probability of occurrence was along rivers and far from human settlements. The highest probability of occurrence was in the south, central and north-eastern parts of GNP whilst in SVC the highest probability was in the far north and far south of the conservancy (Figure 6.21). Therefore, whilst MaxEnt was chosen due to its suitability for small sample sizes, wild dog sample sizes may be suitable per pack, but not for all collared dog in a reserve.

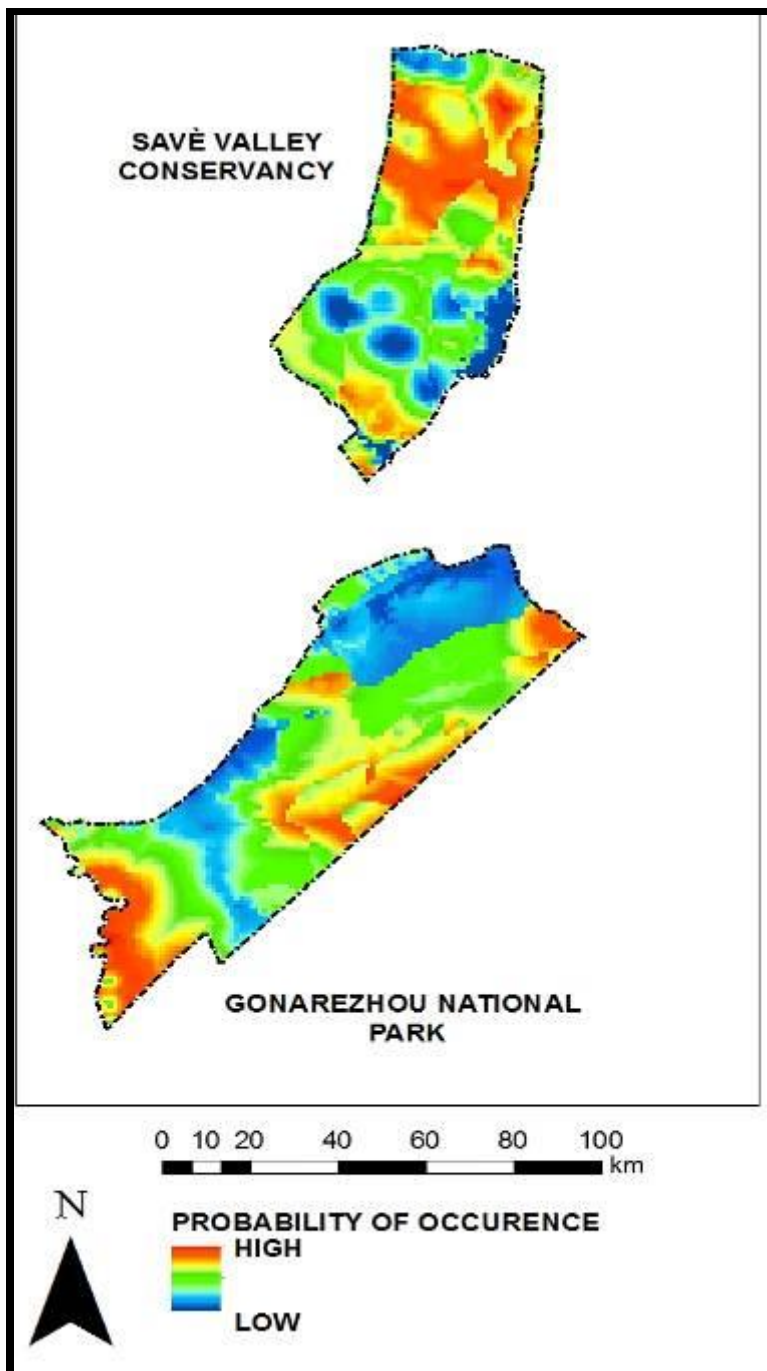


Figure 6.21 GNP and SVC wild dog probability distribution mapped with MaxEnt using red to blue to show highest to lowest probability of occurrence

6.3 MODEL ACCURACY

To assess the accuracy of the model, MaxEnt uses graphs showing an analysis of omission/commission and ROC AUC. Omission/commission graphs for wild dog models showed that accuracies differed between reserves (Figure 6.22) and packs (Appendix H). In the graphs, the red

(training) line and blue (testing) line show how well the model fit to training data and testing data respectively (Syphard & Franklin 2009) with the ideal fit being values closer to one. The green and blue lines show the model's mean omission on test data predictive power and the black line shows the models' predicted omission. The further top left of the graph the test data is, the better the model was at predicting the presences contained in the test sample of the data (Phillips 2006). If the green line is higher than the black line, then the model would have performed worse than a random model. In GNP, omission on test samples was a very good match for the predicted omission rate. However, omission/commission graphs for SVC showed that omission on test samples was poor which would suggest that test and training data were spatially autocorrelated.

MaxEnt also uses ROC AUC to show the model's measure of "sensitivity vs specificity" (Phillips, Anderson & Schapire 2006) where sensitivity is represented by wild dog true positive records and the specificity is the true negative records. Therefore, the ROC AUC is calculated using the product of sensitivity by one minus specificity and a value closer to 1.0 shows more accurate model performance than values closer to 0.5 (Rakotomamonjy 2004; Johnson 2007; Peterson, Papes & Soberón 2008). Both GNP and SVC had only presence data such that MaxEnt used the "fraction of the total study area predicted present" of the "fraction of absences predicted present" (Elith et al. 2006; Phillips 2006) to calculate ROC AUC values for each model discussed further in the following section.

The omission/commission errors and ROC AUC were assessed in the study, to ensure that the model evaluation did not have false evaluations due to incorrectly calibrated data following Hertzog, Bernard & Jay-Robert (2014)'s findings. The study found that smaller samples had higher omission/commission than the larger samples. This confirmed that false positive presence data used for testing and training and the resulting predicted area depend on the data's threshold (Phillips & Elith 2013) mostly because MaxEnt work better with smaller samples (Phillips 2006). Similar to Lobo, Jiménez-Valverde, & Hortal (2010) and Jiménez-Valverde (2012)'s findings the study also concluded that in potential distributions, not only the ROC AUC values are important but the errors of omission and commission are also important as the weight of commission errors is higher than omission errors. This is mostly because commission/omission errors are based on a threshold value where if prediction value is above threshold then an area is suitable and if prediction value is lower than threshold then the area is unsuitable (Phillips & Dudík 2008).

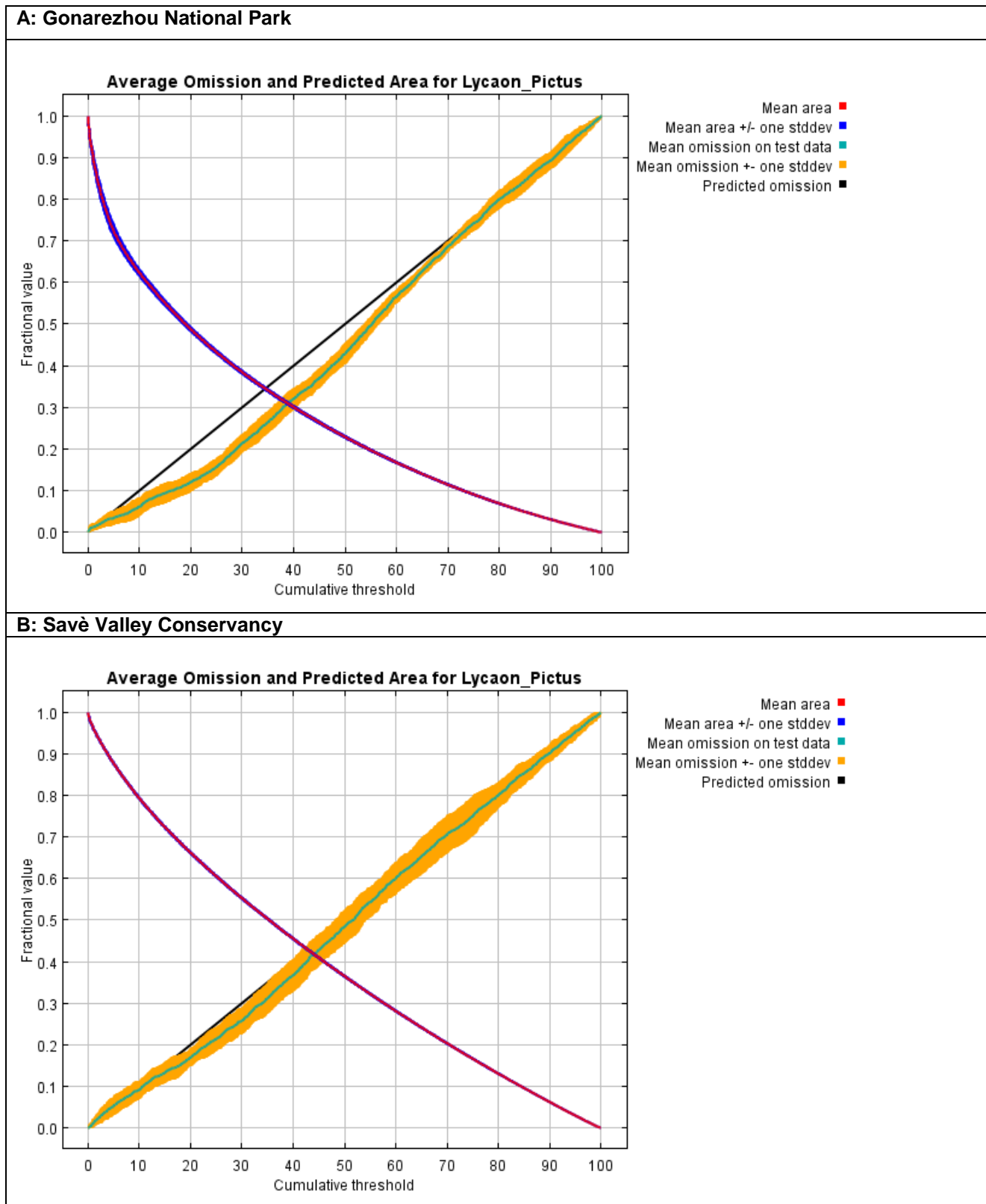


Figure 6.22 MaxEnt model's omission/commission graphs for GNP (A) with a fractional value of 0.6, and SVC (B)

In addition, ROC AUC increases as the ratio of presences and absences decreases meaning a ROC AUC value can be very high simply due to a large number of pseudo absences found in MaxEnt (Bradley 1997; Rakotomamonjy 2004; Phillips, Anderson & Schapire 2006). Assessing the

accuracy of the model's using both commission/omission error and ROC AUC confirmed the importance of cross-validating results (Peterson, Papes & Soberón 2008; Gusset et al. 2009) but failed to confirm the superiority of cross-validating the results with evidence based approaches (Hernandez et al. 2006) due to limited field work. In addition, omission rate is calculated based on the input data (Johnson 2007) which may increase error to the model.

6.4 CONCEPTUAL CORRIDORS

Running the model outside GNP and SVC showed that the model's omission on the test samples were fitting for the predicted omission rate of wild dog distribution because the error commission/omission graphs had the test data in the far left of the graph and lower mean omission than predicted omission. Response curves showed that wild dog movement decreased with distance from human settlements and reserve boundaries but had a constant distribution with distance from the rivers. In addition, movement in elevation was lower in areas above 800 m whilst the movement in vegetation type varied. Error of omission/commission graphs, response curves, and jackknife test for the final model run to identify wild dog corridors outside GNP and SVC can be found in Appendix J. Variables permutation importance showed that the most influential variables were distance from reserve boundary and elevation, whilst the least influential was distance to rivers (Figure 6.23). This was a different sequence of importance to the ones shown inside the parks, but had a ROC AUC value of 0.84 which showed high accuracy.

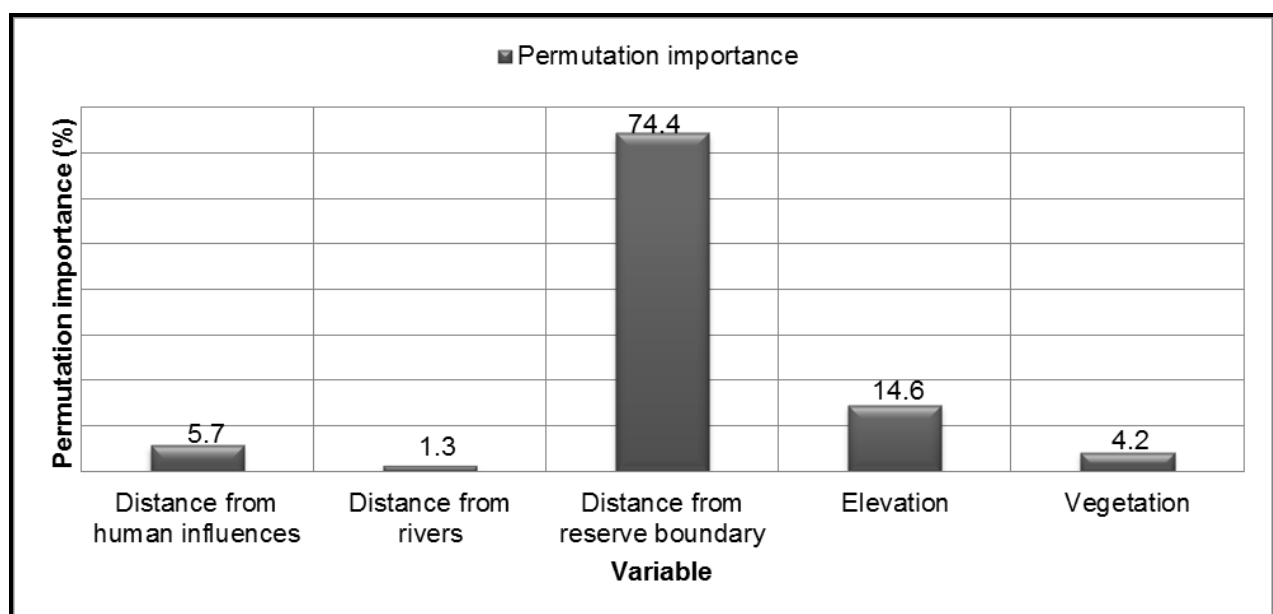


Figure 6.23 Variable permutation importance in MaxEnt distribution model for areas outside GNP and SVC in south-eastern Zimbabwe

BIOMOD SDM showed the same results for the variables' importance (Figure 6.24) where the distance to the reserve boundary and elevation were the most important variables and rivers were the least important variable. These models' ROC AUC values were also high with GAM having 0.85, GLM had 0.83, and MaxEnt had 0.87.

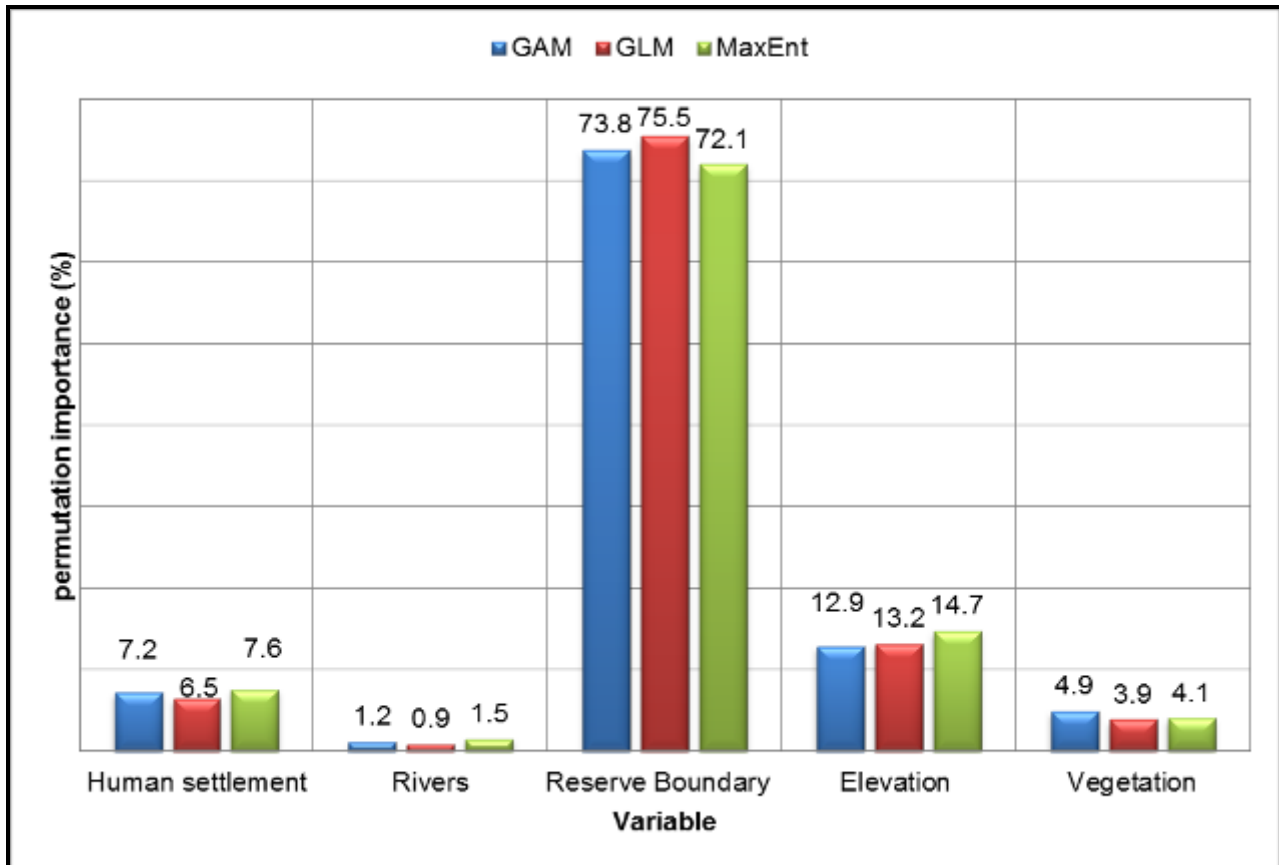


Figure 6.24 Variable permutation importance in BIOMOD's GAM, GLM, and MaxEnt distribution models for areas outside GNP and SVC in south-eastern Zimbabwe

The model's variable importance shows that the distance outside reserves is important in identifying additional areas for wild dog habitats. The study suggests that this is because links between the reserves would facilitate "re-connection" of fragmented habitat and enhance wild dog population growth. This confirmed that areas outside the reserve boundary are important as they form an interface between a species and its potential habitat (DeFries, Karanth & Pareeth 2010). In addition, the study also found that whilst human settlements influence wild dog distribution, it would seem that wild dog could co-exist with humans in areas with suitable habitat as found by Forsyth et al. (2014).

Using the same blue-to-red symbology discussed above, probability distribution for wild dog outside GNP and SVC's borders showed that in south-eastern Zimbabwe, wild dog did have areas where there was probability of occurrence. Highest probability (red) was in areas mostly to the south and south-west of the reserves such as Beitbridge, Chipinge, and Zaka districts (Figure 6.25). Moderate distribution (green) was also found in areas mostly surrounding the reserves as well as in areas that were predicted to have high probability distribution such as Bikita, Chimanimani, Masvingo, and Mwenenzi districts (Figure 6.25).

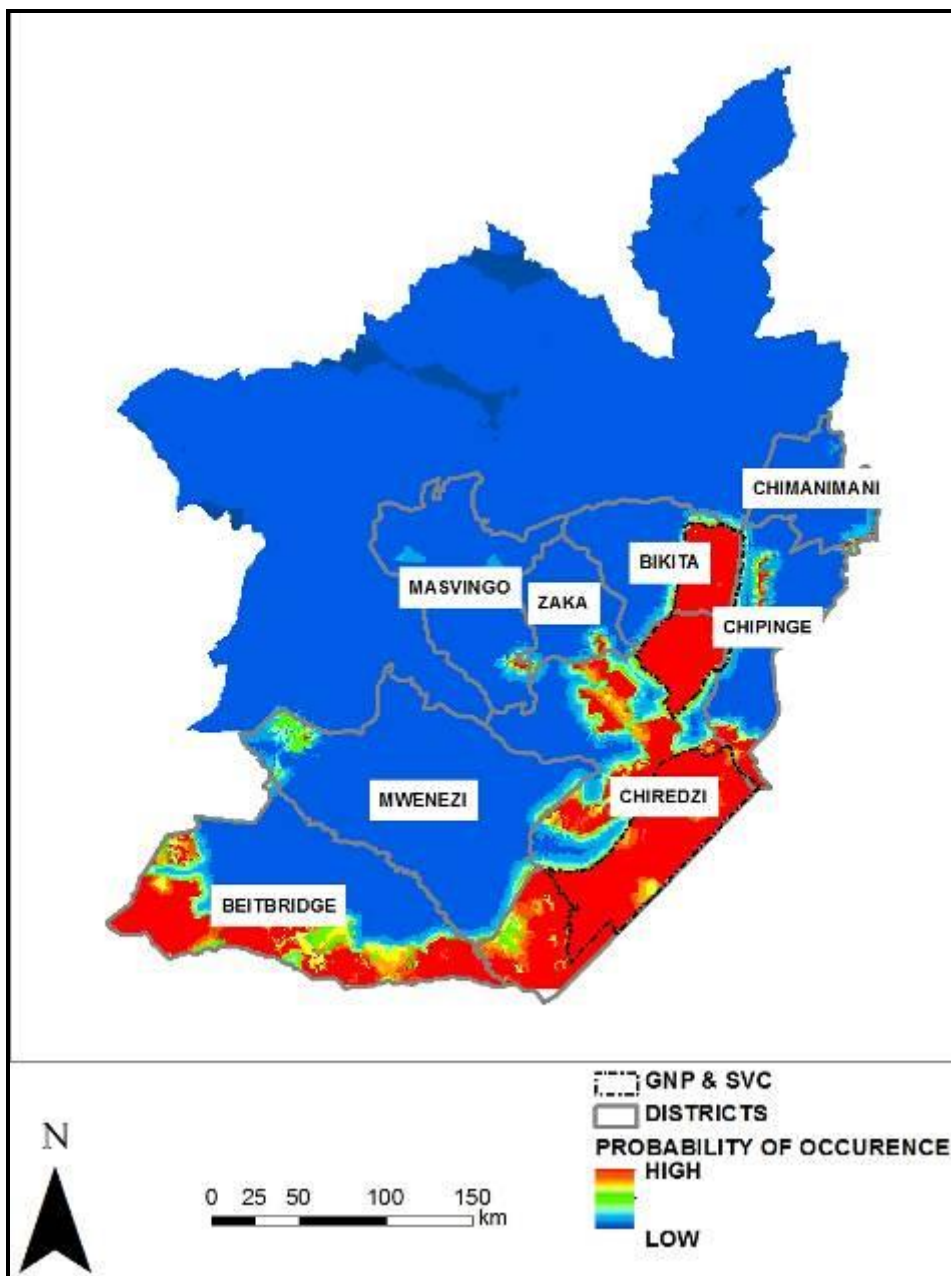


Figure 6.25 South-eastern Zimbabwe wild dog probability distribution outside the border of GNP and SVC mapped with MaxEnt using red to blue to show highest to lowest probability of occurrence

The identified wild dog corridor between GNP and SVC was Malilangwe, which is a wildlife reserve that lies in between GNP and SVC (Figure 6.26). The most probable challenge for connection between GNP and SVC through Malilangwe is that the reserve is fenced (Dalu et al. 2013). This is unfortunate as Malilangwe already has smaller populations of wild dog, which would provide mating partners for the wild dogs in GNP and SVC and thereby increase their populations. However, the fences are there because of extreme poaching in the area of species such as elephants to fund the Mozambican war (Kaschula 2004). Poaching is usually not a threat to wild dogs, but they are affected by traps set for other species such as snares for cheetah and leopard (Traill 2003). Another challenge in the Malilangwe reserve would possibly be the presence of humans for tourism inside the reserve as well as re-settlers around the reserve (Wolmer, Chaumba & Scoones 2003). As such, a secondary route that might sufficiently connect GNP and SVC would be through Chiredzi River to the north-west of Malilangwe, through Chilonga and Chibwedziva to the south (Figure 6.26).

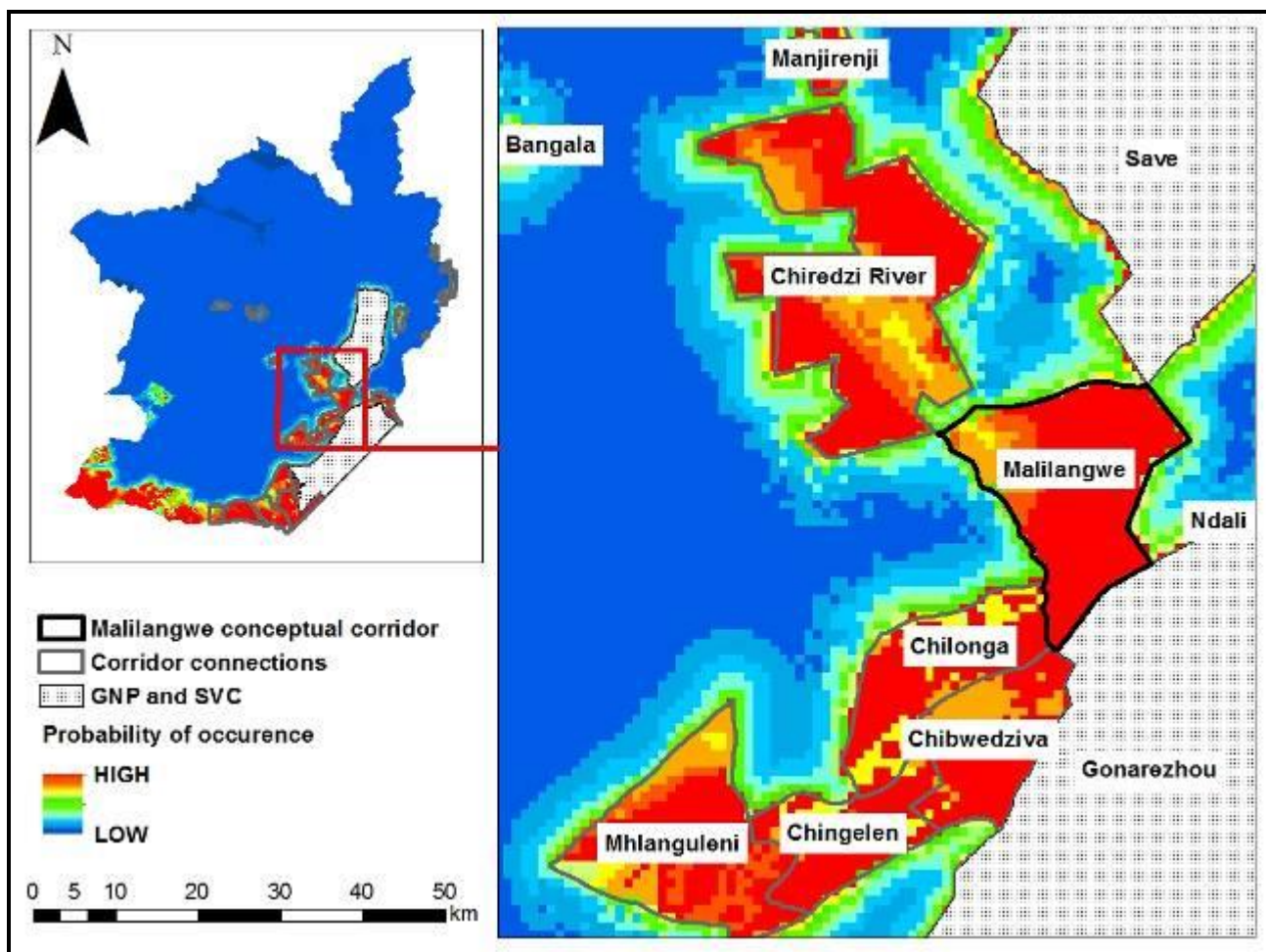


Figure 6.26 Malilangwe conceptual corridor connecting GNP and SVC

As a method, MaxEnt managed to correlate the geographical use of space by species (Guisan & Thuiller 2005; Elith et al. 2006) and their environmental needs (Austin 2007; Zimmerman et al. 2010) to produce predictions of wild dog in south-eastern Zimbabwe. The models' predictions were considered accurate and unbiased because the model managed to confirm the presence of wild dog in GNP and SVC and predicted high probability of occurrence in Malilangwe which was confirmed through literature. This highlighted how weighted average and mean consensus methods show considerable promise for different conservation biological and bio-geographical applications (Marmion et al. 2009). Models such as MaxEnt can be used to predict the chances that a species will be in an area based on studied areas (Phillips, Anderson & Schapire 2006). The study showed that MaxEnt's use with smaller scales was as much its advantage as its disadvantage as there is no threshold for appropriate sample sizes, which may have led to biased results in the case of samples from SVC. Whilst statistically the model accurately managed to identify Malilangwe corridor outside GNP and SVC in Mwenezi and Zaka districts, as well as possible sites for re-introduction of wild dog in northern Mwenezi, Masvingo and Beitbridge the models' practical accuracy could not be confirmed with field based results. Therefore, the study concurs with Jiménez-Valverde, Lobo & Hortal (2008) conclusions on SDM that the difference between potential and realised distribution, effect of the relative occurrence of the species and general inaccuracy of the realised distribution should all be considered when assessing a SDM's output.

CHAPTER 7: ARE SDM SUITABLE FOR IDENTIFYING CONCEPTUAL WILD DOG CORRIDORS?

Wild dog declining populations because of the rapid loss and fragmentation of their habitat created the focus of the study. Whilst SDM have been applauded for their effectiveness in modelling and predicting species distributions, their major criticism has been their inability to integrate the fundamental components of the ecological niche theory on which species studies should be based. Therefore, the study used a combination of methods to try including these components in mapping additional habitat for wild dog outside of GNP and SVC. Chapter eight concludes the study by highlighting the main results based on the objectives, discussing the study's evaluation, and suggesting further research avenues.

7.1 CONCLUSIONS

Three main lessons were learnt in the study with using SDM in ecological studies. Firstly, the chosen SDM should complement the sample data of the species because SDM are calibrated such that inputting data into an SDM will output results, but their accuracy may depend on sample size. Secondly, to incorporate the ecological niche theory into SDM, it is necessary to combine the modelling method with other methods such as UDs mapping and variable assessment in order to capture the components of the niche theory and in turn, get the possible results out of the model. Thirdly, SDM require cross-validation of results preferably in the field because whilst a model may have high statistical accuracy, verification of results is necessary due to factors such as data input in the study being outdated or technical issues limiting the applicability of the model.

Applying the SDM to identify wild dog corridors in south-eastern Zimbabwe showed that with 0.84 accuracy, Malilangwe could serve as a corridor between GNP and SVC through Zaka district in Masvingo province. In addition, there were areas that could possibly serve as relocation sites of wild dog in Beitbridge, Masvingo and Mwenezi districts. Conclusions on the objectives used to satisfy this aim are discussed below. Finally, the model illustrated that variable importance for the wild dog's movement differed inside the reserves and outside where

in the reserves that most influential variable was distance from human settlements and outside it was the distance to reserve boundaries.

7.2 RE-VISITING OBJECTIVES

The literature highlighted that wild dog have become eradicated from their previous home-ranges and are continuing to face high risks of extinction from the few areas where they remain. This is largely due to habitat loss and fragmentation, which is aided by numerous factors such as human-wild dog conflict as well as predation by larger carnivores. Conceptualizing and eventually implementing wild life corridors has been discussed as a counter measure for wild life's habitat fragmentation and loss. Corridors for keystone species such as wild dog and other large carnivores is a conservational strategy whereby providing the conservational needs of a large carnivore also influences the conservation of smaller and dependent species due to space use characteristics of larger carnivores and their interaction with other species. Whilst wild dog biology and ecology have been studied quite extensively, modelling their distribution requires further work.

Denning is an important wild dog ecological process because denning determines population growth and causes wild dog movement and distribution patterns to alter during the denning season. Denning determines population growth based on how successful it is in a season. If a large number of pups make it out of the den strong enough join the pack adults and yearlings, then the pack size and in turn overall population of wild dog in an area increases. However, if few pups make it out of the den due to a variation of factors ranging from disease to predation, then the pack size does not grow and neither does overall population. Denning seasons for different packs occur at around the same time but do not have fixed beginning and end dates just like the den sites are usually within wild dog home-ranges but can change in between denning seasons or even within the same denning seasons. During the denning season wild dog movements change from widespread and far ranging movements to distances of just above 20 km from the den sites for about three months during the cold and dry season of every year.

Wild dog UD's have different geographic and temporal characteristics in between seasons. Whilst during the cold and dry season, they have UD's as small as 10 000 m² and their movement

becomes clustered, during the hot and wet season, their UD's can be as large as more than 600 km² and their movements are wide-spread. In the hot and wet season, wild dog core areas not only increase in number but also become dispersed and corresponding temporal distributions alter mostly between high frequency of visits for short durations and low frequency of visits for long durations. This is a result of wild dog hunting and general "play" as described in the literature. Comparisons between males and females suggest UD's size may be gender based with females having larger UD's and more core areas than the males particularly during the denning seasons. This difference also spilled over into the temporal distributions where the male wild dog characteristically spent shorter periods in their core areas whereas females spent shorter times at the peripheries of their UD's.

Only eight of the numerous variables that influence wild dog movement and distribution patterns were discussed in the study, three as explanatory variables for their geographic distribution, and the other five for their environmental distribution. Wild dog responses to variables differed in the reserves and this is most likely due to more wild dog being collared in SVC than in GNP and for longer periods, or because of conservation measures being more effective in one reserve. Whilst wild dog in GNP steered clear of human settlements, wild dog in SVC moved fairly close to the human settlements, which may be explained by people's perceptions of wild dog in the reserves and the extent of human-wild dog conflict. In both reserves, wild dog did not seem to view roads as barriers to their movement, mostly moved within 10 km of the rivers in both seasons, and did not venture far from the reserve boundaries except slightly in the cold and dry season. The environmental variables showed different responses between the two reserves mostly due to different ranges and types in the reserves but common trends were identified. Wild dog seemed to prefer areas with higher elevations in the cold and dry season, moved in grasslands and less dense areas in both seasons, mostly moved in areas that received lower rainfall and were oblivious to temperature. In defining wild dog distribution, roads and rivers were highly autocorrelated whilst elevation, rainfall, and temperature were also highly autocorrelated.

7.3 STUDY EVALUATION

Strengths and weaknesses of the study were weighed against the ecological niche theory and the results show that whilst the study's methodological approaches had limitations, these were outweighed by the study's theoretical and practical value. The ecological niche theory aims to

map “*The region that has the right set of biotic and abiotic factors and that is accessible to the species, and is equivalent to the geographic distribution of the species*” (Soberón & Peterson 2005:3). This is done by identifying the species accessible areas, regions with the right interacting species and suitable biotic and abiotic factors within their fundamental niche. Areas accessible to wild dog were based on wild dog collar data in the study. A controlled sample size based on the collared dog could be used even though collar data occasionally had missing data for different packs due to collar recycling, malfunctions, or death of dog. This was not a major challenge as wild dog had been collared for more than two years, had high frequency readings of collar readings, which decreases spatial errors and collars were replaced mostly within the same pack such that the study had continuous data for the same pack albeit with gaps.

Whilst the study did not include wild dog interactions with other species, this was compensated by use of predictor variables described in literature as driving factors for wild dog prey and predators. These variables were also assessed as the suitable biotic and abiotic factors to determine wild dog niche although, mostly due to data constraints surrogate data was used for variables such as vegetation density and climate data had a large temporal difference to collar data. The study also had methodological limitations because of using a model that assumed equilibrium between a species distribution and the environment (De Marco, Diniz-Filho & Bini 2008) which is unlikely in reality due to events such as on-going habitat fragmentation. However, this was done to fit wild dog model into the conceptual framework of the niche theory. As such, the study managed to analyse wild dog movement and distribution patterns within their ecological framework using three different methods to cater for the dimensions of the ecological niche theory to map their potential distribution with high probability accuracy, heedless of the limitations the study had.

7.4 RECOMMENDATIONS

Identifying wild dog potential home-range using SDM is an effective method that can be refined in order to produce higher probability accuracies, and understand wild dog ecology further. The study showed that T-LoCoH is an effective way of modelling wild dog UD and its correlation of geographic and temporal distributions should be explored further for use in mapping den locations and durations based on changes in wild dog re-visitation rate and durations of stay.

The study suggests that whilst there is value in mapping wild dog movement and distribution based on packs, studies that will include differences in UD extents and variable response between sexes would be more beneficial in trying to counter declining populations. The study postulates using the methods discussed above on collared male and female dog from different parks and packs, for sex specific modelling to assist in planning for new pack formation based on migrating females and males.

In conclusion, the study showed that MaxEnt is a useful approach for mapping species probabilities with small sample sizes. This illustrated that SDM are useful in modelling wild dog distribution. Further work should be done on the variables that influence the model, particularly including wild dog interaction with prey and predators and correlating wild dog movement data with concurrent rainfall and temperature data. Analysing changes in both biotic and abiotic variables over time (for example, yearly) and the response in wild dog movements to these changes is another area where work should be done to identify how the changes in land cover and use over time affect wild dog movement and distribution patterns. The predictive ability of different SDM should be tested further on wild dog collar data in more varied landscapes to identify trends and similarities as well as differences. To explore the accuracy of the SDM on modelling wild dog distribution, the Malilangwe conceptual corridor and additional habitat areas identified by the study should be tested for suitability using such as the VORTEX method proposed by Bach et al. (2009) in combination with the Gusset et al. (2009) approach on wild dog re-location. More work should be done on the conservational benefits of connecting GNP and SVC through Malilangwe as a conservation area in south- eastern Zimbabwe.

(36 442 words)

REFERENCES

- Alfredéén A-C 2006, Denning behaviour and movement pattern during summer of wolves *Canis lupus* on the Scandinavian Peninsula – master thesis, SLU
- Allen D A 2010. *GIS Tutorial 2: Spatial Analysis Workbook*. 2nd ed. California: ESRI Press
- Almany GR, Connolly SR, Heath DD, Hogan JD, Jones G P, McCook LJ, Mills M, Pressey RL & Williamson DH 2009. Connectivity, biodiversity conservation and the design of marine reserve networks for coral reefs. *Coral Reefs* 28:339–351.
- Andrew M E, Wulder M A & Coops N C 2011. Patterns of protection and threats along productivity gradients in Canada. *Biological Conservation* 144: 2891–2901.
- Angulo E, Rasmussen G S A, Macdonald D W & Courchamp 2013. Do social groups prevent Allee effect related extinctions?: The case of wild dog. *Frontiers in Zoology* 10:1-13.
- Araújo M B & Guisan A 2006. Five (or so) challenges for species distribution modelling. *Journal of Biogeography* 33: 1677–1688.
- Araújo M B & Williams P H 2000. Selecting areas for species persistence using occurrence data. *Biological Conservation* 96: 331-346.
- Austin M 2007. Species distribution models and ecological theory: A critical assessment and some possible new approaches. *Ecological modelling* 200: 1–19.
- Austin M P 2002. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. *Ecological modelling* 157:101-118.
- Austin M P & Van Niel K P 2011. Improving species distribution models for climate change studies: variables selection and scale. *Journal of Biogeography* 38(1):1-8.
- Bach L A, Pedersen R B F, Hayward M, Stagegaard, Loeschcke V & Pertoldi C 2009. Assessing re-introductions of the African Wild dog (*Lycaon pictus*) in the Limpopo Valley Conservancy, South Africa, using the stochastic simulation program VORTEX *Journal for Nature Conservation* 18:237-246.
- Bauer H 2003. Lion Conservation in West and Central Africa: Integrating social and natural science for wildlife conflict resolution around Waza National Park, Cameroon. PhD Thesis. Leiden University, Institute for Environmental Science.
- Becker P A, Miller P S, Gunther M S, Somers M J, Wildt D E, Maldonado J E 2012. Inbreeding avoidance influences the viability of reintroduced populations of African Wild Dog (*Lycaon pictus*). *Plos one* 7(5):1-11.
- Beger M, Grantham HS, Pressey RL, Wilson KA, Peterson EL, Dorfman D, Mumby PJ, Lourival R, Brumbaugh DR & Possingham HP 2010. Conservation planning for

- Conservation planning for connectivity across marine, freshwater, and terrestrial realms. *Biological Conservation* 143: 565–576.
- Beier P, Majka D R & Newell S L 2009. Uncertainty analysis of least-cost modelling for designing wildlife linkages. *Ecological Applications* 19(8): 2067–2077.
- Bennett AF & Saunders DA 2010. Habitat fragmentation and landscape change [online]. Oxford:Oxford University. Available from <http://ukcatalogue.oup.com/product/9780199554249.do> [Accessed 15 March 2013].
- Bocchino C 2007. Landmines and Conservation in Southern Africa: Peace Parks in the Aftermath of Armed Conflict. *African Security Review* 16(2) 78-93.
- Bodin O & Saura S 2010. Ranking individual habitat patches as connectivity providers : Integrating network analysis and patch removal experiments. *Ecological Modelling* 221: 2393-2406.
- Bowman J L, Kochanny C O, Demarais S & Leopold B D 2000. Evaluation of a GPS collar for white-tailed deer. *Wildl Soc Bull* 28:141–145.
- Bradley A P 1997. The use of the area under the roc curve in the evaluation of machine learning algorithms. *Pattern Recognition* 30(7): 1145-1159.
- Bucklin D N, Basille M, Benschoter A M, Brandt L A, Mazzotti F J, Romañach S S, Speroterra C & Watling J I 2014. Comparing species distribution models constructed with different subsets of environmental predictors. *Diversity and distributions* 1-13.
- Buettner U K, Davies-Mostert H T, du Toit J T & Mills M G L 2006. Factors affecting juvenile survival in African wild dog (*Lycaon pictus*) in Kruger National Park, South Africa. *Journal of Zoology* 272:10–19.
- Buisson L, Thuiller W, Casajusn, Lek S & Grenouillet G 2009. Uncertainty in ensemble forecasting of species distribution. *Global Change Biology* 16: 1145–1157.
- Burrows R 2011. A Guide to the African Wild Dog (30 June 2011) [online]. London: George Adamson Wildlife Preservation Trust. Available from http://www.georgeadamson.org/content/view.cfm/downloads/burrows_110630.pdf [Accessed 13 May 2014].
- Büscher B & Schoon M 2009. Competition Over Conservation: Collective Action and Negotiating Transfrontier Conservation in Southern Africa, *Journal of International Wildlife Law & Policy* 12(1-2) 33-59.
- Calenge C 2006. The package “adehabitat” for the R software: A tool for the analysis of space and habitat use by animals. *Ecological modelling* 197:516-519.

- Caley P, Tennant P & Hood G 2011. Modelling the distribution of vertebrate pests in New South Wales under climate change. Office Report. Canberra: Invasive Animals Cooperative Research Centre.
- Calhome 1994. *Calhome MSDOS Release 1.0*. Kie John. [Online Help]. Online available: <http://www.nhsbig.inhs.uiuc.edu>.
- Caro T, Jones T & Davenport TRB 2009. Realities of documenting wildlife corridors in tropical countries. *Biological Conservation* 142: 2807–2811.
- Caryl F M, Hahs A K, Lumsden L F, Van der Ree R, Wilson C & Wintle B A 2014. Continuous predictors of species distributions support categorically stronger inference than ordinal and nominal classes: an example with urban bats. *Landscape ecology* 29:1237-1248.
- Chadil N, Rusameesawang A & Keeratiwintakorn P 2008. *Real-time tracking management system using GPS, GPRS and Google earth*. Proceedings of the 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology held 14-17 May 2008, Bangkok, Thailand. North Bangkok: Department of Electrical Engineering King Mongkut's University of Technology.
- Chang A Y, Parrales M E, Jimenez J, Sobieszczyk M E, Hammer S M, Copenhaver D J & Kulkarni R P 2009. *Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries*. *International Journal of Health Geographics* 8: 49.
- Chang K-T 2006. *Introduction to Geographic Information Systems*. 2nd ed. Michigan: McGraw-Hill Higher Education.
- Chape S, Harrison J, Spalding M & Lysenko I 2006. Measuring the extent and effectiveness of reserves as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society* 360: 443–456.
- Chefaoui R M 2011. Applying species distribution modelling for the conservation of Iberian protected invertebrates. PhD Thesis. Madrid: Autonomous University Madrid, Department of Biodiversity and Evolutionary Biology.
- Chetkiewicz CLB & Boyce MS 2009. Use of resource selection functions to identify conservation corridors. *Journal of Applied Ecology* 46: 036–1047.
- Cloutier T L & Packard J M 2014. Enrichment options for African painted dog (*Lycaon pictus*). *Zoo Biology* 33:475-480.
- Conlisk E, Syphard A D, Franklin J, Flint L, Flint A & Regan H M 2013. Management implications of uncertainty in assessing impacts of multiple landscape-scale threats to

- species persistence using a linked modelling approach. *Global Change Biology* 3(3):858-869.
- Courchamp F & Macdonald D W 2001. Crucial importance of pack size in the African wild dog *Lycaon pictus*. *Animal Conservation* 4: 169–174.
- Courchamp F, Rasmussen G S A & Macdonald D W 2002. Small pack size imposes a trade-off between hunting and pup guarding in the painted hunting dog *Lycaon pictus*. *Behavioural ecology* (13) 20-27.
- Cowling R M, Pressey R L, Sims-Castley R, Le Roux A, Baard E, Burgers C J & Palmer G 2003. The expert or the algorithm?—comparison of priority conservation areas in the Cape Floristic Region identified by park managers and reserve selection software. *Biological Conservation* 112: 147–167.
- Creel C & Creel N M 2002. *The African Wild Dog: Behavior, Ecology and Conservation*, Unites States: Princeton University Press.
- Cumming G S & Corneils D 2012. Quantitative comparison and selection of home-range metrics for telemetry data. *Diversity and Distributions* 1–9.
- Cushman S A 2010. Animal movement data: GPS telemetry, autocorrelation and the need for path level analysis. In Cushman S A & Huettmann F (eds) *Spatial complexity, informatics, and wildlife conservation*, 131–149. Tokyo: Springer Japan.
- Cuthill I 1991. Field experiments in animal behaviour: methods and ethics. *Animal behaviour* 42 (6)1007-1014.
- D'eon R G & Delparte D 2006. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. *Journal of Applied Ecology* 42 (2) 383-388.
- Dalu T, Thackeray Z, Leuci R, Clegg B, Chari L C & Nhiwatiwa T 2013. First results on bathymetry, stratification and physicochemical limnology of a small tropical African reservoir (Malilangwe, Zimbabwe) *Water SA* [online], 39 (1). Available from: <http://dx.doi.org/10.4314/wsa.v39i1.12> [Accessed 12 October 2014].
- Darnell A M, Graf J A, Somers M J, Slotow R & Szykman Gunther M 2014. Space use of African wild dog in relation to other large carnivores. *PLoS ONE* 9(6): 1-9.
- Davies-Mostert H T, Kamler J F, Mills M G L, Jackson C R, Rasmussen G S A, Groom R J & Macdonald D W 2012. Long-distance transboundary dispersal of African wild dog among reserves in southern Africa. *African Journal of Ecology* 50:500-506.
- Davies-Mostert H T, Mills M G L & Macdonald D W 2013. Hard boundaries influence African wild dog diet and prey selection. *Journal of Applied Ecology* 50:1358– 1366.

- De Marco Jr P, Diniz-Filho J A F & Bini 2008. Spatial analysis improves species distribution modelling during range expansion. *Biology letters* 4:577-580.
- DeFries R, Karanth K K & Pareeth S 2010. Interactions between reserves and their surroundings in human-dominated tropical landscapes. *Biological conservation* 143:2870- 2880.
- DeMatteo K E & Loiselle B A 2008. New data on the status and distribution of the bush dog (*Speothos venaticus*): Evaluating its quality of protection and directing research efforts. *Biological Conservation* 141: 2494-2505
- Dixon J A & Sherman PB 1991. Economics of Reserves. *Environmental Economics* 20(2) 68-74.
- Du Toit R 2006. Implementation of a rhino endowment model for community participation in rhino conservation, SVC, Zimbabwe. *Pachyderm* 39: 114-116.
- Edren S M C, Wisz M S, Teilmann J, Dietz R & Soderkvist J 2010. Modelling spatial patterns in harbour porpoise satellite telemetry data using maximum entropy. *Ecography* 33: 698-708.
- Elith J & Graham C H 2009. Do they? How do they? Why do they differ? On finding reasons for differing performances of species distribution models. *Ecography* 32: 66-77.
- Elith J, Graham C H, Anderson R P, Dudík M, Ferrier S, Guisan A, Hijmans R J, Huettman F, Leathwick J R, Lehmann A, Li J, Lohmann I G, Loiselle B A, Manion G, Moritz C, Namakura M, Nakazawa Y, McC Overton J, Townsend Peterson A, Phillips S J, Richardson K, Scachetti-Pereira R, Schapire R E, Soberón J, Williams S, Wisz M S & Zimmerman N E 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129-151.
- Elith J & Leathwick J R 2009. Species Distribution Models: Ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics* 40:677-697.
- Elith J, Phillips S J, Hastie T, Dudík M, Chee Y E & Yates C J 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17:43-57.
- Epps CW, Mutayoba BM, Gwin L & Brashares JS 2011. An empirical evaluation of the African elephant as a focal species for connectivity planning in East Africa. *Biodiversity research* 17: 603-612.
- Erikse A, Wabakken P, Zimmermann B, Andreassen H P, Arnemo J M, Gundersen H, Milner J M, Liberg O, Linnell J, Pedersen H C S, Solberg E J & Storaas T 2009. Encounter

- frequencies between GPS-collared wolves (*Canis lupus*) and moose (*Alces alces*) in a Scandinavian wolf territory. *Ecological research* (24) 3: 547-557.
- ESRI 2010. *ArcGIS Desktop: Release 10*. Environmental Systems Research Institute.
- Ferrier S, Drielsma M, Manion G & Watson G 2002. Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. II. Community-level modelling. *Biodiversity and Conservation* 11: 2309–2338.
- Field A 2007. *Discovering statistics using SPSS*. 3rd ed. London: SAGE Publications.
- Flacke G, Becker P, Cooper D, Szykman Gunther M, Robertson I, Holyoake C. Donaldson R & Warren K 2013. An infectious disease and mortality survey in a population of free-ranging African wild dog and sympatric domestic dog. *International journal of biodiversity* 1-13.
- Forsyth D M, Woodford L, Moloney P D, Hampton J O & Woolnough A P 2014. How does a carnivore guild utilise a substantial but unpredictable anthropogenic food source? Scavenging on hunter-shot ungulate carcasses by wild dog/dingoes, red foxes and feral cats in south-eastern Australia revealed by camera traps. *PLoS ONE* 9(6): 1-14.
- Frair J L, Fieberh J, Cagnacci F, DeCesare N J & Pedrotti L 2010. Resolving issues of imprecise and habitat-biased locations in ecological analyses using GPS telemetry data. *Philosophical transactions of the royal society biological sciences* 365 (1550) 2187-2200.
- Franklin J, Wejnert K, Hathaway S, Rochester C & Fisher R 2009. Effect of species rarity on the accuracy of species distribution models for reptiles and amphibians in southern California. *Diversity and Distributions*, 15: 167-177.
- Frantzen M A J, Ferguson J W H & de Villiers M S 2001. The conservation role of captive African wild dog (*Lycaon pictus*). *Biological Conservation* 100:253-260.
- Gandiwa E & Kativu S 2009. Influence of fire frequency on *Colophospermum mopane* and *Combretum apiculatum* woodland structure and composition in northern Gonarezhou National Park, Zimbabwe. *Koedoe* 51(1): 1-13.
- Gandiwa E, Magwati T, Zisadza P, Chinuwo T & Tafangenyasha C 2011. The impact of African elephants on *Acacia tortilis* woodland in northern Gonarezhou National Park, Zimbabwe. *Journal of Arid Environments* 75:809-814.
- Gandiwa P, Matsvayi W, Ngwenya MM & Gandiwa E 2011. Assessment of livestock and human settlement encroachment into the northern Gonarezhou National Park, Zimbabwe. *Journal of Sustainable Development in Africa* 13(5) 19-33.
- Geomatica 2013. *Geomatica version 10.3*. PCI Geomatics Enterprises, Inc. [Online Help].

- Getz W M & Wilmsen C C 2004. A local nearest-neighbour convex-hull construction of home-ranges and utilization distributions. *Ecography* 27:489-505.
- Getz W M, Ryan S J, Lyons A J, Cross P C, Fortmann-Roe S & Wilmsen C C 2007. LoCoH: Nonparametric Kernel Methods for Constructing Home-ranges and Utilization Distributions. *Plos One* 2(2): 1-12.
- GME 2012. *Geospatial Modelling Environment ArcGIS 10.1 Release R3.1.1*. Beyer Hawthorne. [Online Help]. Online available: <http://www.nhsbig.inhs.uiuc.edu>.
- Goldman M 2009. Constructing Connectivity: Conservation Corridors and Conservation Politics in East African Rangelands. *Annals of the Association of American Geographers* 99:2, 335- 359
- Gordon A, Simondson D, White M, Moilanen A & Bekessy S A 2009. Integrating conservation planning and landuse planning in urban landscapes. *Landscape and Urban Planning* 91: 183–194.
- Graf J A, Gusset M, Reid C, Janse van Rensburg S, Slotow R & Somers M J 2006. Evolutionary ecology meets wildlife management: artificial group augmentation in the re-introduction of endangered African wild dog (*Lycaon pictus*). *Animal conservation* 9:398-403.
- Graham M D, Douglas-Hamilton I, Adams WM & Lee PC 2009. The movement of African elephants in a human-dominated land-use mosaic. *Animal conservation* 12: 445–456.
- Groom R J (rosemary@africanwildlifeconservationfund.org) 2013a. RE: Project proposal. Email to K R Marembo (17401097@sun.ac.za) (12 May 2013).
- Groom R J (rosemary@africanwildlifeconservationfund.org) 2013b. RE: Update. Email to K R Marembo (17401097@sun.ac.za) (27 November 2013).
- Groom R J (rosemary@africanwildlifeconservationfund.org) 2014. RE: Wild dog dens. Email to K R Marembo (krmarembo@gmail.com) (16 May 2014).
- Guisan A & Thuiller W 2005. Predicting species distribution: offering more than simple habitat models. *Ecology letters* 8: 993–1009.
- Gurrutxaga M, Lozano P J & Barrio G 2010. GIS-based approach for incorporating the connectivity of ecological networks into regional planning. *Journal for Nature Conservation* 18: 318–326.
- Gusset M & Macdonald D W 2010. Group size effects in cooperatively breeding African wild dog. *Animal behaviour* 79:425-428.
- Gusset M, Jakoby O, Müller M S, Somers M J, Slotow R & Grimm V 2009. Dog on the catwalk: Modelling re-introduction and translocation of endangered wild dog in South Africa. *Biological conservation* 142:2774-2781.

- Gusset M, Stewart G B, Bowler D E & Pullin A S 2010. Wild dog reintroductions in South Africa: A systematic review and cross-validation of an endangered species recover programme. *Journal for Nature Conservation* 18:230-234.
- Gusset M, Swarner M J, Mponwane L, Keletile K & McNutt J W 2009. Human–wildlife conflict in northern Botswana: livestock predation by Endangered African wild dog *Lycaon pictus* and other carnivores. *Fauna & Flora International* 43(1): 67–72.
- Hayes T 2006. Parks, People, and Forest Protection: An institutional assessment of the effectiveness of reserves. *World Development* 34(12): 2064–2076.
- Hayward M W, Adendorff J, O’Brein J, Sholto-Douglas A, Bissett C, Moolman L C, Bean P, Fogarty A, Howarth D, Slater R & Kerley I H 2007. The reintroduction of large carnivores to the Eastern Cape, South Africa: an assessment. *Onyx* 41(2):205-214.
- Hayward M W, Hayward G J, Druce D J & Kerley G I H 2009. Do fences constrain predator movements on an evolutionary scale? Home-range, food intake and movement patterns of large predators reintroduced to Addo Elephant National Park, South Africa. *Biodiversity and Conservation* 18: 887-904.
- Hayward M W, O’Brien J, Hofmeyr M & Kerley G I H 2006. Prey preferences of the African wild dog *Lycaon pictus* (canidae: 126 odelling): ecological requirements for conservation. *Journal of Mammalogy* 87(6):1122–1131.
- Herfindal I, Linell J D C, Odden J, Nilsen E B & Andersen R 2006. Prey density, environmental productivity and home-range size in the Eurasian lynx (*Lynx lynx*). *Journal of Zoology* 265:63-71.
- Hernandez P A, Graham C H, Master L L & Albert D L 2006. The effect of sample size and species characteristics on performance of different species distribution modelling methods. *Ecography* 29: 773-786.
- Hertzog L R, Bernard A & Jay-Robert P 2014. Field validation shows bias-corrected pseudo-absence selection is the best method for predictive species-distribution modelling. *Diversity and distributions* 1-11.
- Hijmans R J, Cameron J L, Parra P G & Jarvis A 2006. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965-1978.
- Hollard J D, Bert D G & Fahrig L 2004. Determining the spatial scale of species’ response to habitat. *BioScience* 54 (3): 227-233.
- HomeRange 1996. *HomeRange MacOS Release 2.0*. Huber Robert & Bradbury Jack. [Online Help]. Online available: <http://www.nhsbig.inhs.uiuc.edu>.

- Hunter S C, Gusset M, Miller L J & Somers M J 2014. Space use as an indicator of enclosure appropriateness in African wild dog (*Lycaon pictus*). *Journal of applied animal welfare science* 17:98-110.
- Jachowski D S, Millspaugh J J, Biggind D E, Livieri T M & Matchett 2010. Home-range size and spatial organization of black-footed ferrets *Mustela nigripes* in South Dakota, USA. *Wildlife Biology* 16:66-76.
- Jackson C R, Power R J, Groom R J, Masenga E H, Mjingo E E, Fyumagwa R D, Røskoft E & Davies-Mostert H 2014. Heading for the Hills: Risk Avoidance Drives Den Site Selection in African Wild Dogs. *PlosOne* 9(6): 1-5.
- Jantke K & Scheinder U A 2010. Multiple-species conservation planning for European wetlands with different degrees of coordination. *Biological Conservation* 143 :1812–1821.
- Jiménez-Valverde A 2012. Insights into the area under the receiver operating characteristic curve (ROC AUC) as a discrimination measure in species distribution modelling. *Global Ecology and Biogeography* 21:498-507.
- Jiménez-Valverde A, Lobo J M & Hortal J 2008. Not as good as they seem: the importance of concepts in species distribution modelling. *Diversity and distributions* 14:885-890.
- Johnson D D & Ganskopp D C 2008. GPS collar sampling frequency: effects on measures of resource use. *Rangeland Ecological Management* 61:226-231.
- Johnson D S, London J M, Lea M-A & Durban J W 2008. Continuous-time correlated random walk model for animal telemetry data. *Ecology* 89:1208–1216.
- Johnson M 2007. *A gentle introduction to Maximum Entropy Models and their friends*. [Online]. Online available: <http://www.science.mq.edu.au>.
- Karanth K K & DeFries R 2010. Conservation and management in human-dominated landscapes: Case studies from India. *Biological conservation* 143:2865-2869.
- Kaschula A 2004. Elephants and their impact on the woody component of sandveld vegetation communities in the Malilangwe Wildlife Reserve, south eastern lowveld, Zimbabwe. Master's thesis. Harare: University of Zimbabwe, Department of Geography and Environmental Science.
- Kearney M & Porter W 2009. Mechanistic niche modelling: combining physiological and spatial data to predict species ranges. *Ecology Letters* 12: 334–350.
- KernelHR 1997. *KernelHR MSDOS Release 4.27*. Seaman Erran. [Online Help]. Online available: <http://www.nhsbig.inhs.uiuc.edu>.

- Kissui B M 2008. Livestock predation by lions, leopards, spotted hyenas and their vulnerability to retaliatory killing in the Maasai steppe, Tanzania. *Animal conservation* 11:422-432.
- Klein C, Wilson K, Watts M, Stein J, Berry S, Carwardine J, Smith M S, Mackey B & Possingham H 2009. Incorporating ecological and evolutionary processes into continental-scale conservation planning. *Ecological applications* 19.1:206–217.
- Koper N & Manseau M 2009. Generalized estimating equations and generalized linear mixed-effects models for modelling resource selection. *Journal of Applied Ecology* 46: 590–599.
- Kratt C & Kratt M 2013 (Producers and Directors). Be the creature-African wild dogs. (DVD). Okavango: Kratt Bros: Be the Creature.
- Langford W T, Gordon A, Bastin L 2009. When do conservation planning methods deliver? Quantifying the consequences of uncertainty. *Ecological Informatics* 4 :123–136.
- Laurenson M K & Caro T M 1994. Monitoring the effects of non-trivial handling in free-living cheetahs. *Animal behaviour* 47 (3): 547-557.
- Le Mar K & McArthur C 2000. Relocating radio-collared targeted marsupials after a 1080-poisoning operation. *Tasforests* 12: 155-160.
- Leigh K A 2005. The ecology and conservation biology of the endangered African wild dog (*Lycaon pictus*), in the Lower Zambezi, Zambia. University of Sydney, Faculty of Veterinary Science PhD.
- Lin J P 2008. A Metric and GIS Tool for Measuring connectivity among habitat patches using least-cost distances. Office Report. Vicksburg: EMRRP Technical Notes Collection. ERDC TN- EMRRP-EBA-02 – Ecosystem Management Restoration and Research Program.
- Lindsey P, du Toit JT & Mills MGL 2004. The distribution and population status of African wild dog (*Lycaon pictus*) outside reserves in South Africa. *South African Journal of Wildlife Research* 34(2): 143–151.
- Lindsey PA, Romañach SS, Tambling CJ, Chartier K & Groom R 2011. Ecological and financial impacts of illegal bushmeat trade in Zimbabwe. *Fauna & Flora International*, 45(1), 96–111.
- Lobo J M, Jiménez-Valverde A & Hortal J 2010. The uncertain nature of absences and their importance in species distribution modelling. *Ecography* 33:103-114.
- Longley P A, Goodchild M, Maguire D J & Rhind D W 2006. Geographic Information Systems and Science

- Lyons A, Turner W C & Getz W M 2013. Home-range plus: A space-time characterization of movement over real landscapes. *BMC Movement Ecology* 1:2, doi:10.1186/2051-3933-1-12.
- Madej J 2001. Cartographic design using ArcView GIS. Word pressed. Canada.
- Maling D H 2004. Coordinate Systems and Map Projections for GIS. Lecture presented at University of Maine on GIS Applications, Maine <http://www.spatial.maine.edu/~beard/Lectures510/Projections%2004.pdf>
- Margules C R & Pressey RL 2000. Systematic conservation planning. *Nature* 405: 243-253.
- Marmion M, Parviainen M, Luoto M, Heikkinen R K & Thuiller W 2009. Evaluation of consensus methods in predictive species distribution modelling. *Diversity and distributions* 15:59-69.
- Marsden CD, Mable BK, Woodroffe R, Rasmussen GSA, Cleaveland S, McNutt W, Emmanuel M, Thomas R & Kennedy L J 2009. Highly Endangered African Wild Dog (*Lycaon pictus*) Lack Variation at the Major Histocompatibility Complex. *Journal of heredity* S54-S66.
- Marsden CD, Wayne RK, Woodroffe R, Mills MGL, McNutt JW, Creel S, Groom RJ, Massenga E, Cleaveland S, Kat P, Rasmussen G, Lines R, Andre J-M, Begg C, & Mable BK 2011. Demographic processes determine patterns of genetic diversity across wild dog populations. *Submitted: Molecular Ecology*.
- Mbizah MM & Groom RJ 2011. Diet choice of African wild dog and competition with other large carnivores in Zimbabwe's SVC. *Submitted: South African Journal of Wildlife Research*.
- Mbizah MM, Joubert CJ, Joubert L & Groom RJ 2014. Implications of African wild dog (*Lycaon pictus*) denning on the density and distribution of a key prey species: addressing myths and misperceptions. *Biodiversity conservation* 23:1441-1451.
- McNutt J W & Silk J B 2008. Pup production, sex ratios, and survivorship in African wild dog, *Lycaon pictus*. *Behavioural Ecological Sociobiological* 62:1061-1067.
- Mellin C, Mengersen K, Bradshaw C J A & Caley M J 2014. Generalizing the use of geographical weights in biodiversity modelling. *Global Ecology and Biogeography* 23:1314-1323.
- Meyburg B & Meyburg C 2009. Wanderung mit Rucksack: Satellitentelemetrie bei Vögeln. *Der Falke* 56: 256–263.
- Mills M G L & Gorman M L 1997. Factors affecting the density and distribution of wild dog in the Kruger National Park. *Conservation Biology* 11(6):1397-1406.

- Mitchell A 1999. The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns and Relationships
- Mollenhauer R, Wagner T, Kepler M V & Sweka J A 2013. Fall and Early Winter Movement and Habitat Use of Wild Brook Trout. *Transactions of the American Fisheries Society* 142(5): 1167-1178.
- Morrison J C, Sechrest W, Dinerstein E, Wilcove D S & Lamoreux J F 2007. Persistence of large mammals faunas as indicators of global human impacts. *Journal of Mammalogy* 88(6): 1363-1380.
- Mouton J 2001. *How to succeed in your masters and doctoral studies: A South African guide and resource book*. Pretoria: Van Schaik Publishers.
- Movebank 2014. What is animal tracking? Movebank for Animal Tracking Data Repository. Online available: <https://www.movebank.org/node/857>.
- Munthali SM 2007. Transfrontier conservation areas: Integrating biodiversity and poverty alleviation in Southern Africa. *Natural Resources Forum* 31:51–60.
- Newmark W 2008. Another milestone in conservation literature. *Conservation Biology* 22(1): 224-236.
- Nonaka Y 2011. Response of breeding wolves to human disturbance on den sites – an experiment. PhD Thesis. Sweden: Uppsala University and Grimsö forskningsstation, Biology Education Centre.
- Nyathi D (dnyathi@painteddog.org) 2013. RE: Information on wild dog conservation efforts. Email to K R Marembo (17401097@sun.ac.za) (06 June 2013).
- Packer C, Kosmala M, Cooley H S, Brink H, Pintea L, garshelis D, Purchase G, Strauss M, Swanson A, Balme G, Hunter L & Nowell K 2009. Sport hunting , predator control and conservation of large carnivores. *PlosOne* 4(6): 1-15.
- Patterson B D, Kasiki S M, Selempo E & Kays R W 2004. Livestock predation by lions (Panther leo) and other carnivores on ranches neighboring Tsavo National Parks, Kenya. *Biological conservation* 119:507-516.
- Pearce J L & Boyce M S 2006. Modelling distribution and abundance with presence only data. *Journal of applied ecology* 43: 405–412.
- Pearson R G 2011. Species' Distribution Modeling for Conservation Educators and Practitioners. Office report. Network of Conservation Educators and Practitioners. Lessons in Conservation 54 – 89.
- Pebsworth P A, Morgan H R & Huffman M A 2011. Evaluating home-range techniques: use of Global Positioning System (GPS) collar data from chacma baboons. *Primates* 1: 16-25.

- Peterson A T, Papes M & Soberón J 2008. Rethinking receiver operating characteristic analysis applications in ecological niche modelling. *Ecological Modelling* 213: 63–72.
- Phillips S J & Dudík M 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* 31: 161-175.
- Phillips S J & Elith J 2013. On estimating probability of presence from use–availability or presence–background data. *Ecology* 94:1409–1419.
- Phillips S J, Anderson R P & Schapire R E 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling* 190 (3-4): 231-259.
- Phillips S 2006. *A brief tutorial on Maxent*. AT & T Research. Available at:<http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc>.
- Pierre J P & Higuchi H 2006. Satellite tracking in avian conservation : applications and results from Asia. *Landscape and Ecological Engineering*, 1: 33–42.
- Pittiglio C, Skidmore AK, Van Gils HAMJ & Prins HHT 2012. Identifying transit corridors for elephant using a long time-series. *International journal of applied earth observation and geoinformation* 14:61–72.
- Platts P J, Garcia R A, Hof C, Foden W, Hansen L A, Rahbek C & Burgess N D 2014. Conservation implications of omitting narrow-ranging taxa from species distribution models, now and in the future. *Diversity and distributions* 20:1307-1320.
- Pole A, Gordon IJ, Gorman ML & MacAskill M 2004. Prey selection by African wild dog (*Lycaon pictus*) in southern Zimbabwe. *Journal of Zoology London* 262: 207–216.
- Pressey R L & Bottrill M C 2009. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. *Fauna & Flora International, Oryx*, 43(4): 464–476.
- Pressey RL, Cabeza M, Watts ME, Cowling RM & Wilson KA 2007. Conservation planning in a changing world. *Trends in ecology and evolution* 22(11): 583-592.
- Rakotomamonjy A 2004. Optimizing Area Under Roc Curve with SVMs. Paper delivered at the Modelling, Computation and Optimization Conference, Metz.
- Rasmussen G S A & Macdonald D W 2011. Masking of the zeitgeber: African wild dog mitigate persecution by balancing time. *Journal of Zoology* 286: 232–242.
- Rasmussen G S A 1997. Conservation Status of the Painted Hunting Dog (*Lycaon pictus*) in Zimbabwe. DNPWLM/Painted Dog Research Project, Harare, Zimbabwe.
- Roever C L, van Aarde R J & Leggett K 2013. Functional connectivity within conservation networks: Delineating corridors for African elephants. *Biological Conservation* 157: 128–136.

- Romañach S S & Lindsey P A 2007. Conservation implications of prey responses to wild dog *Lycaon pictus* during the denning season on wildlife ranches. *Animal conservation* 11:111-117.
- Rondini C & Chiozza C 2010. Quantitative methods for defining percentage area targets for habitat types in conservation planning. *Biological Conservation* 143: 1646–1653.
- Rouget M, Cowling R M, Lombard A T, Knight A T & Kerley I H 2006. Designing large-scale conservation corridors for patterns and processes. *Conservation Biology* 20, 2: 549–561.
- Rubio L & Saura S 2012. Assessing the importance of individual habitat patches as irreplaceable connecting elements: An analysis of simulated and real landscape data. *Ecological Complexity* 11: 28-37.
- Saura S, Vogt P, Velázquez J, Hernando A & Tejera R 2011. Key structural forest connectors can be identified by combining landscape spatial pattern and network analyses. *Forest Ecology and Management* 262 :150–160.
- Seegar W S, Cutchis P N, Fuller M R, Suter J J & Bhatnagar V 1996. Fifteen Years of Satellite Tracking Development and Application to Wildlife Research and Conservation. *John Hopkins APL technical digest* 17(4): 401–411.
- Seo C, Thorne JH, Hannah L & Thuiller W 2009. Scale effects in species distribution models: implications for conservation planning under climate change. *Biology Letters* 5: 39– 43.
- Shannon G, Matthews W S, Page B R, Parker G E & Smith R J 2009. The affects of artificial water availability on large herbivore ranging patterns in modelling habitats: a new approach based on modelling elephant path distributions. *Diversity and Distributions* 15: 776–783.
- Sibanda M 2010. The Urban and Rural Spaces: Consequences of Nature Conservation and the Rural to Urban Migration: A Case of the Great Limpopo Transfrontier Conservation Area, Zimbabwe Sector. *J Sociology Society Anth* 1 (1-2): 23-32.
- Singh S K, Srivastava P K, Gupta M, Thakur J K & Mukherjee S 2013. Appraisal of land use/land cover of mangrove forest ecosystem using support vector machine. *Environmental Earth Sciences* 1-7.
- Smith C S, Epstein J H, Breed A C, Plowright R K, Olival K J, de Jong C, Daszak P & Field H E 2011. Satellite Telemetry and Long-Range Bat Movements. *PloS ONE* 6(2): e14696. Doi:10.1371/journal.pone.0014696.
- Soberón J & Peterson A T 2006. Interpretation of models of fundamental ecological niches and species' distributional areas. *Biodiversity Informatics* 2 :1-10.

- Soechting J F & Flanders m 1992. Moving in three-dimensional space: frames of reference, vectors, and coordinate systems. *Annual review of neuroscience* 15: 167-191.
- Spenceley A 2006. Tourism in the Great Limpopo Transfrontier Park. *Development Southern Africa* 23(5): 649-667.
- SPSS 2014. *SPSS for Windows Release 20*. SPSS Inc. [Online Help]. Online available: <http://www.spss.com>.
- Stockwell D R B & Peterson A T 2001. Effects of sample size on accuracy of species distribution models. *Ecological modelling* 148:1-13.
- Stoy P C, Williams M, Spadavecchia L, Bell R A, Prieto-Blanco A. Evans J G & van Wijk M T 2009. Using Information Theory to Determine Optimum Pixel Size and Shape for Ecological Studies: Aggregating Land Surface Characteristics in Arctic Ecosystems. *Ecosystems* 12 (4) 574-589.
- Straub J, Marsh R, Togerson D & Korvald C 2013. RoofSat: Teaching Students Skills for Software Development for GIS Data collection and Other Activities. *2nd Annual North Dakota Space Robotics Forum*.
- Sutmoller P, Thomson GR, Hargreaves SK, Foggin CM & Anderson EC 2000. The foot-and-mouth disease risk posed by African buffalo within wildlife conservancies to the cattle industry of Zimbabwe. *Preventive Veterinary Medicine* 44:43-60.
- Svenning JS, Fløjgaard C, Marske KA, Nógues-Bravo D & Normand S 2011. Applications of species distribution modelling to paleobiology. *Quaternary Science Reviews* xxx: 1-18.
- Swanson A, Caro T, Davies-Mostert H, Mills M G L, Macdonald D W, Borner M, Masenga E & Packer C 2014. Cheetahs and wild dog show contrasting patterns of suppression by lions. *Journal of animal ecology* 1-10.
- Syphard A D & Franklin J 2009. Differences in spatial predictions among species distribution modelling methods vary with species traits and environmental predictors. *Ecography*, 32: 907-918.
- Tafangenyasha C 1997. Tree loss in the Gonarezhou National Park (Zimbabwe) between 1970 and 1983. *Journal of Environmental Management* 49: 355–366.
- Taubman M T, Leaf R B, McEachin J J, Papovich S & Leaf J B 2013. A comparison of data collection techniques used with discrete trial teaching. *Research in Autism Spectrum Disorders* 7(9) 1026–1034.
- Taylor P D, Fahrig L & With K A 2006. Landscape connectivity: A return to the basics. In *Connectivity conservation*, ed. K. R. Crooks and M. Sanjayan, 29-43. Cambridge, UK: Cambridge University Press.

- Teel T L & Manfredo M J 2009. Understanding the Diversity of Public Interests in Wildlife Conservation. *Conservation Biology* 24 (1): 128–139.
- Thaker M, Vanak A T, Owen C R, Ogden M B, Niemann S M & Slotow R 2011. Minimizing predation risk in a landscape of multiple predators: effects on the spatial distribution of African ungulates. *Ecology* 92 (2): 398-407.
- Theuerkauf J, Rouys S & Jedrzejewski W 2003. Selection of den, rendezvous, and resting sites by wolves in the Biolowieza Forest, Poland. *Canadian Journal of Zoology*, 1:163-167.
- Thiebot J, Cherel Y, Crawford R J M, Makhado A B, Trathan P N, Pina U D D & Bost C A 2013. A Space Oddity: Geographic and Specific Modulation of Migration in *Eudyptes* Penguins. *Plos one* 8(8): 1-13.
- Tomlinson R 2006. Thinking about GIS: Geographic Information System Planning for Managers. 3rd ed. California: ESRI Press.
- Traill L 2003. Habitat partitioning and an assessment of habitat suitability using presence data, of a large herbivore community on a Zimbabwean private wildlife reserve. Master's thesis. Stellenbosch: Stellenbosch University, Department of Conservation and Ecology.
- Van der Lande K & Viljoen M 2013. Origins of PeaceParksFoundations. *Lis-link* [online]. Available from: <http://www.peaceparks.co.za/story.php?pid=1&mid=2> [Accessed 15 March 2013].
- Van der Meer E, Rasmussen G S A, Muvengwi J & Fritz H 2013. Foraging costs, hunting success and its implications for African wild dog (*Lycaon pictus*) conservation inside and outside a protected area. *African journal of applied Ecology* 52:69-76.
- Vanak A T & Gompper M E 2010. Interference competition at the landscape level: the effect of free-ranging dog on a native mesocarnivores. *Journal of applied Ecology* 47:1225-1232.
- Vanak A T, Fortin D, Thaker M, Ogden M, Owen C, Greatwood S & Slotow 2013. Moving to stay in place: behavioural mechanisms for coexistence of African large carnivores. *Ecology* 94:2619-2631.
- Van Niekerk A 2010. A comparison of land unit delineation techniques for land evaluation in the Western Cape, South Africa. *Land Use policy* 27 (3): 937-945.
- Villard M-A & Jonsson BG 2009. Tolerance of focal species to forest management intensity as a guide in the development of conservation targets. *Forest Ecology and Management* 258S :S142–S146.

- Visconti P & Elkin C 2009. Using connectivity metrics in conservation planning – when does habitat quality matter? *Diversity and Distributions* 15: 602–612.
- Warren D L & Seifert S N 2011. Ecological niche modelling in Maxent: the importance of model complexity and the performance of model selection criteria. *Ecological Applications* 21:335-342.
- Watermeyer J (jess@africanwildlifeconservationfund.org) 2014. RE: Assistance. Email to K R Marembo (krmarembo@gmail.com) (06 October 2014).
- Webster H, McNutt J W & McComb K 2013. African wild dog as a fugitive species: playback experiments investigate how wild dog respond to their major competitors. *Ethology* 118:147-156.
- Whittington-Jones B, Parker D & Davies-Mostert H 2011. *Factors influencing potential dispersal routes of African Wild Dog in northern KwaZulu-Natal*. Proceedings of the SAWAM symposium held 18-21 September 2011. University of Stellenbosch: Southern African Wildlife Management Association.
- Wierda N 2010. Parental care and movement patterns of wolves (*Canis lupus*) during summer. Bachelor thesis. Van Hall Larenstein University of Applied Sciences, 35pp
- Wilkie D S, Morelli G A, Demmer J, Starkey M, Telfer P & Steil M 2006. Parks and People: Assessing the human welfare effects of establishing reserves for biodiversity conservation. *Conservation Biology* 20 (1): 247–249.
- Wilson R P, Shepard E L C & Liebsch N 2008. Prying into the intimate details of animal lives: use of a daily diary on animals. *Endangered Species Research*, 4: 123-137.
- Wis M S, Hijmans R J, Li J, Peterson A T, Graham C H, Guisan A & NCEAS Predicting Species Distributions Working Group 2008b. Effects of sample size on the performance of species distribution models. *Diversity and Distributions* 14: 763–773.
- Wis M, Dendoncker N, Madsen J, Rounsevell M, Jespersen M, Kuijken E, Courtens W, Verschuur C & Cottaar F 2008a. Modelling pink-footed goose (*Anser brachyrhynchus*) wintering distributions for the year 2050: potential effects of land-use change in Europe. *Diversity and Distributions* 14: 721–731.
- Withey J C, Bloxton T D & Marzluff J M 2001. Effects of tagging and location error in wildlife radiotelemetry studies. *Radio tracking and animal populations* 43-75.
- Wolmer W, Chaumba J & Scoones I 2003. Wildlife Management and Land Reform in South-eastern Zimbabwe: A Compatible Pairing or a Contradiction in Terms? *Sustainable Livelihoods in Southern Africa Research Paper 1*, Institute of Development Studies, Brighton.

- Woodroffe R & Donnelly C A 2011. Risk of contact between endangered African wild dog *Lycaon pictus* and domestic dog: opportunities for pathogen transmission. *Journal of applied ecology* 48:1345-1354.
- Woodroffe R & Frank L G 2006. Lethal control of African lions (*Panthera leo*): local and regional population impacts. *Animal Conservation* 8(1): 91-98.
- Woodroffe R & Ginsberg J R 1998. Edge effects and the extinction of populations inside reserves. *Science* 280: 2126-2128.
- Woodroffe R & Sillero-Zubiri C 2012. *Lycaon pictus*. IUCN Red list of threatened species. IUCN 2012 [online], 2012(2). Available from <http://www.iucnredlist.org> [Accessed 18 April 2013].
- Woodroffe R 2010. Ranging behaviour of African wild dog packs in a human –dominated landscape. *Journal of Zoology* 283:88-97.
- Woodroffe R, Davies-Mostert H, Ginsberg J, Graf J, Leigh K, McCreery K, Mills G, Pole A, Rasmussen G, Robbins R, Somers M & Szykman M 2007. Rates and causes of mortality in Endangered African wild dog *Lycaon pictus*: lessons for management and monitoring. *Oryx* 41(2), 215–223.
- Woodroffe R, Lindsey P, Románach S, Stein A & ole Ranah S M K 2006. Livestock predation by endangered African wild dog (*Lycaon pictus*) in northern Kenya. *Biological conservation* 124:225-234.
- Woodroffe R, Prager K C, Munson L, Conrad P A & Dubovi E J 2012. Contact with domestic dog increases pathogen exposure in endangered African Wild Dog (*Lycaon pictus*). *PLoS ONE* 7(1):1-9.
- Wu G, van der Helm F C T, Veegar H E J, Makhsous M, Van Roy P, Anglin C, Nagels J, Karduna A R, McQuade K, Wang X, Werner F W & Buchholz B 2006. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics* 38 (5) 981–992.
- Young N, Carter L & Evangelista P 2011. *A MxEnt model v3.3.3e Tutorial (ARCGIS v 10)*. Colorado State University. Available at : http://www.ibis.colostate.edu/WebContent/WS/ColoradoView/TutorialDownloads/A_MaxENT_Model_v8.pdf
- Zimmerman NE, Edwards TC, Graham CH, Pearman PB & Svenning JC 2010. New trends in species distribution modelling. *Ecography* 33: 985-989.

PERSONAL COMMUNICATIONS

- Groom R J (rosemary@africanwildlifeconservationfund.org) 2013. RE: Project proposal. Email to K R Marembo (17401097@sun.ac.za) (12 May 2013).
- Groom R J (rosemary@africanwildlifeconservationfund.org) 2013. RE: Update. Email to K R Marembo (17401097@sun.ac.za) (27 November 2013).
- Groom R J (rosemary@africanwildlifeconservationfund.org) 2014. RE: Wild dog dens. Email to K R Marembo (krmarembo@gmail.com) (16 May 2014).
- Nyathi D (dnyathi@painteddog.org) 2013. RE: Information on wild dog conservation efforts. Email to K R Marembo (17401097@sun.ac.za) (06 June 2013).
- Watermeyer J (jess@africanwildlifeconservationfund.org) 2014. RE: Assistance. Email to K R Marembo (krmarembo@gmail.com) (06 October 2014).

APPENDICES

APPENDIX A: T-LOCOH SCRIPT IN R FOR WILD DOG PACKS.....	157
APPENDIX B: BIOMOD SCRIPT IN R FOR THE WILD DOG PACKS	159
APPENDIX C: ADDITIONAL T-LOCOH GEOGRAPHICAL AND TEMPORAL DISTRIBUTIONS WILD DOG PACKS	162
APPENDIX D: WILD DOG RE-VISITATION RATES AND DURATION OF STAY PLOTTED USING ISOPLETHS COLOUR CODE AND CORRESPONDING MAPS IN DIFFERENT SEASONS	166
APPENDIX E: MAXENT RESPONSE CURVES RESULTS PER PACK	181
APPENDIX F: MAXENT VARIABLES JACKKNIFE TESTS RESULTS PER PACK	186
APPENDIX G: MAXENT VARIABLE PERMUTATION IMPORTANCE PER PACK	189
APPENDIX H: MAXENT OMISSION/COMMISSION GRAPHS RESULTS PER PACK ..	190
APPENDIX I: MAXENT WILD DOG DISTRIBUTION MODELS PER PACK.....	193
APPENDIX J: MAXENT WILD DOG DISTRIBUTION OUTSIDE GNP AND SVC OUTPUTS.....	198
APPENDIX K: ETHICAL CLEARANCE.....	200

APPENDIX A: T-LOCOH SCRIPT IN R FOR WILD DOG PACKS

```

R version 3.0.2 (2013-09-25) -- "Frisbee Sailing"
Copyright (C) 2013 The R Foundation for Statistical
Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)
R is free software and comes with ABSOLUTELY NO
WARRANTY.
You are welcome to redistribute it under certain
conditions.
Type 'license()' or 'licence()' for distribution details.
Natural language support but running in an English
locale
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in
publications.
Type 'demo()' for some demos, 'help()' for on-line
help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
> #load tlocoh into R
> require(tlocoh)
Loading required package: tlocoh
T-LoCoH for R (version 1.16)
URL: http://tlocoh.r-forge.r-project.org/
Warning message:
package 'tlocoh' was built under R version 3.0.3
> #load GPS points from shapefile
> require(maptools)
Loading required package: maptools
Loading required package: sp
Checking reeos availability: TRUE
> fn <- ("G:/28-02-2014/Methods Rose/Wild dog
Seasonal/SVC Seasonal/BatanaiHW.shp")
> BatanaiHW <- readShapePoints(fn, verbose=T)
Shapefile type: Point. (1). # of Shapes: 2695
> xvs <- coordinates(BatanaiHW)
> head(xvs)
  coords.x1 coords.x2
0 32.17826 -20.20885
1 32.18090 -20.20030
2 32.19812 -20.19048
3 32.20955 -20.19839
4 32.21446 -20.23170
5 32.20880 -20.23168
> #visualize data
> plot(BatanaiHW[, c("Longitude", "Latitude")],
pch=20)
> #convert coordinates to UTM
> require(sp)
> require(rgdal)
Loading required package: rgdal
rgdal: version: 0.8-11. (SVN revision 479M)
Geospatial Data Abstraction Library extensions to R
successfully loaded
Loaded GDAL runtime: GDAL 1.9.2, released
2012/10/08
Path to GDAL shared files:
C:/Users/Rosebud/Documents/R/win-
librarv/3.0/rgdal/rgdal
GDAL does not use iconv for recoding strings.
Loaded PROJ.4 runtime: Rel. 4.7.1, 23 September
2009. IPJ VERSION: 4701
Path to PROJ.4 shared files:
C:/Users/Rosebud/Documents/R/win-
librarv/3.0/rgdal/proj
> BatanaiHW.sp.latlong <- SpatialPoints(BatanaiHW[,
c("Longitude", "Latitude")],
proj4string=CRS("+proj=longlat +ellps=WGS84"))
> BatanaiHW.sp.utm <-
spTransform(BatanaiHW.sp.latlong, CRS("+proj=utm
+south +zone=37 +ellps=WGS84"))
> BatanaiHW.mat.utm <-
coordinates(BatanaiHW.sp.utm)
> head(BatanaiHW.mat.utm)
  coords.x1 coords.x2
0 -213936.9 7750676
1 -213698.8 7751639
2 -211934.8 7752807
3 -210698.6 7751976
4 -210030.1 7748291
5 -210624.3 7748268
> #change column headings to x and y
> colnames(BatanaiHW.mat.utm) <- c("x", "y")
> head(BatanaiHW.mat.utm)
      x      y
0 -213936.9 7750676
1 -213698.8 7751639
2 -211934.8 7752807
3 -210698.6 7751976
4 -210030.1 7748291
5 -210624.3 7748268
> #collecting timestamps
> names(BatanaiHW)
[1] "Unit_ID" "Date__GMT_" "Longitude" "Latitude"
"Speed"
[6] "Direction" "Altitude" "PDOP" "GPS_logtim"
> #check time date format in R
> Svs.time()
[1] "2014-06-04 12:26:17 SAST"
> #convert to POSIXct R's class of time values
> class(BatanaiHW$Date__GMT_)
[1] "factor"
> head(as.character(BatanaiHW$Date__GMT_))
[1] "2011-02-21 15:00" "2011-02-21 16:00" "2011-02-
21 17:01" "2011-02-21 23:01"
[5] "2011-02-22 03:00" "2011-02-22 04:00"
> BatanaiHW.gmt <-
as.POSIXct(BatanaiHW$Date__GMT_, tz="UTC")
> BatanaiHW.gmt[1:3]
[1] "2011-02-21 15:00:00 UTC" "2011-02-21 16:00:00
UTC"
[3] "2011-02-21 17:01:00 UTC"
> local.tz <- "Africa/Harare"
> BatanaiHW.localtime <-
as.POSIXct(format(BatanaiHW.gmt, tz=local.tz),
tz=local.tz)
> BatanaiHW.localtime[1:3]
[1] "2011-02-21 17:00:00 CAT" "2011-02-21 18:00:00
CAT"
[3] "2011-02-21 19:01:00 CAT"
> #create locoh-xv objects and check for duplications
> BatanaiHW.lxv <- xvt.lxv(xv=BatanaiHW.mat.utm,
dt=BatanaiHW.localtime, id="AU458",
proj4string=CRS("+proj=utm +south +zone=37
+ellps=WGS84"))
Calculating area and perimeter...Done.
Calculating the time span of each hull...Done.
Identifying enclosed points...Done.
The following hullsets were generated:
AU458.ots2696.k6.s0.04.kmin0
AU458.ots2696.k9.s0.04.kmin0
AU458.ots2696.k12.s0.04.kmin0
AU458.ots2696.k16.s0.04.kmin0
AU458.ots2696.k18.s0.04.kmin0
AU458.ots2696.k21.s0.04.kmin0
AU458.ots2696.k24.s0.04.kmin0
Total time: 27.4 secs
> summarv(BatanaiHW.lhs, compact=T)
Summarv of LoCoH-hullset object: BatanaiHW.lhs
T-LoCoH version: 1.16

```

```
[1] AU458.pts2696.k6.s0.04.kmin0
[2] AU458.pts2696.k9.s0.04.kmin0
[3] AU458.pts2696.k12.s0.04.kmin0
[4] AU458.pts2696.k16.s0.04.kmin0
[5] AU458.pts2696.k18.s0.04.kmin0
[6] AU458.pts2696.k21.s0.04.kmin0
[7] AU458.pts2696.k24.s0.04.kmin0
> #create isopleths for the hulls
> BatanaiHW.lhs <- lhs.iso.add(BatanaiHW.lhs)
Merging hulls into isopleths
AU458.pts2696.k6.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
Loading required package: rgeos
rgeos version: 0.2-20. (SVN revision 413)
GEOS runtime version: 3.3.8-CAPI-1.7.8
Polygon checking: TRUE
AU458.pts2696.k9.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
AU458.pts2696.k12.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
AU458.pts2696.k16.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
AU458.pts2696.k18.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
AU458.pts2696.k21.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
AU458.pts2696.k24.s0.04.kmin0
  Sorting hulls by area...Done.
  Unioning hulls
Total time: 6 secs
> #visualise the isopleths
> plot(BatanaiHW.lhs, iso=T, record=T, ufipt=T)
> #plot isopleth area curves
> lhs.plot.isoarea(BatanaiHW.lhs)
> #plot the isopleth edge:area curves for the different
values of k tested
> lhs.plot.isoear(BatanaiHW.lhs)
> #choose best suited isopleth
> plot(BatanaiHW.lhs, iso=T, k=15, allots=T,
cex.allots=0.1, col.allpts="gray30", ufipt=F)
> #pull out final hulls
> BatanaiHW.lhs.k15 <- lhs.select(BatanaiHW.lhs,
k=15)
> #compute additional hull metrics
> #compute ellipses
> BatanaiHW.lhs.k15 <-
lhs.ellipses.add(BatanaiHW.lhs.k15)
AU458.pts2696.k16.s0.04.kmin0
  Calculating enclosing ellipses
Total time: 1.5 mins
> summarv(BatanaiHW.lhs.k15)
Summary of LoCoH-hullset object: BatanaiHW.lhs.k15
T-LoCoH version: 1.16
[1] AU458.pts2696.k16.s0.04.kmin0
  id: AU458
  pts: 2695
  dates: 2011-02-21 17:00:00 CAT to 2013-04-01
01:00:00 CAT
  movement: tau=7200 (2hs), vmax=0.8966239,
d.bar=3522.588
  hulls: 2695
  duos: 0
  mode: k=15. kmin=0. s=0.04
  metrics: area, ecc, nep, nnn, perim, scg.enc.mean,
scg.enc.sd.
  scg.nn.mean. scg.nn.sd. tspan
  isos: [1] iso.srt-area.iso-q.h2696.i5
```

```
  other: ellipses
> #visualize
> plot(BatanaiHW.lhs.k15, hulls=T, ellipses=T, allpts=T,
nn=T, ttid="auto")
> #compute the time use metric
> BatanaiHW.lhs.k15 <-
lhs.visit.add(BatanaiHW.lhs.k15, ivg=3600*12)
AU458.pts2696.k16.s0.04.kmin0
  1 of 1. Computing the number of visits in each hull for
ivg=43200 (12hs)
> summarv(BatanaiHW.lhs.k15)
Summary of LoCoH-hullset object: BatanaiHW.lhs.k15
T-LoCoH version: 1.16
[1] AU458.pts2696.k16.s0.04.kmin0
  id: AU458
  pts: 2695
  dates: 2011-02-21 17:00:00 CAT to 2013-04-01
01:00:00 CAT
  movement: tau=7200 (2hs), vmax=0.8966239,
d.bar=3522.588
  hulls: 2695
  duos: 0
  mode: k=15. kmin=0. s=0.04
  metrics: area, ecc, mnlv.43200, nep, nnn, nsv.43200,
perim.
  scg.enc.mean, scg.enc.sd, scg.nn.mean,
scg.nn.sd. tspan
  hmap: ivg (43200)
  isos: [1] iso.srt-area.iso-q.h2696.i5
  other: ellipses
> # The summarv report shows the new hull metrics
that have been created with nsv.value as the measure
of re-visitation (number of separate visits for an inter-
visit gap period of seconds). mnlv.value stands for
mean number locations per visit, and is the measure
of average duration.
> #save the work
> lhs.save(BatanaiHW.lhs.k15)
LoCoH-hullset BatanaiHW.lhs.k15 saved as
'BatanaiHW.lhs.k15' to:
G:\28-02-2014\Methods
Rose\R Scripts Tlocoh\Seasonal home-range and
UDs\Hot and wet season\SVC\T-LoCoH
Scripts\AU458.n2696.s0.04.k16.elps.iso.lhs.01.RData
> #Behavior isopleths
> #Create and plot isopleths from hulls sorted by
elongation
> BatanaiHW.lhs.k15 <- lhs.iso.add(BatanaiHW.lhs.k15,
sort.metric="ecc")
Merging hulls into isopleths
AU458.pts2696.k16.s0.04.kmin0
  Sorting hulls by ecc descending...Done.
  Unioning hulls
Total time: 0.3 secs
> plot(BatanaiHW.lhs.k15, iso=T, iso.sort.metric="ecc")
> # Spatial patterns of re-visitation: histogram of re-
visitation and a map of hull parent points colored by
re-visitation rate
> hist(BatanaiHW.lhs.k15, metric="nsv")
> plot(BatanaiHW.lhs.k15, hpp=T, hpp.classify="nsv",
ivg=3600*12, col.ramp="rainbow")
> #blue to purple marks areas with high re-visitation
> #duration of each visit
> hist(BatanaiHW.lhs.k15, metric="mnlv",
ivg=3600*12)
> plot(BatanaiHW.lhs.k15, hpp=T, hpp.classify="mnlv",
col.ramp="rainbow")
> # Create a scatterplot of the hull re-visitation and
duration (will be used as map legend)
> hsp <- lhs.plot.scatter(BatanaiHW.lhs.k15, x="nsv",
v="mnlv", col="spiral", bg="black")
> plot(BatanaiHW.lhs.k15, hpp=T, hsp=hsp,
hpp.classify="hsAaaAAA")
```

APPENDIX B: BIOMOD SCRIPT IN R FOR WILD DOG PACKS

```

R version 3.1.0 (2014-04-10) -- "Spring Dance"
Copyright (C) 2014 The R Foundation for Statistical
Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)
R is free software and comes with ABSOLUTELY NO
WARRANTY.
You are welcome to redistribute it under certain
conditions.
Type 'license()' or 'licence()' for distribution details.
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in
publications.
Type 'demo()' for some demos, 'help()' for on-line
help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
> setwd ("C:\\BIOMODMSC")
> library(biomod2)
Loading required package: sp
Loading required package: raster
Loading required package: parallel
Loading required package: reshape
biomod2 3.1-48 loaded.
Type browseVignettes(package='biomod2') to access
directly biomod2 vignettes.
Warning messages:
1: package 'biomod2' was built under R version 3.1.2
2: package 'sp' was built under R version 3.1.2
3: package 'raster' was built under R version 3.1.2
4: package 'reshape' was built under R version 3.1.2
> DataSpecies <- read.csv
("C:\\BIOMODMSC\\SVC_PA.csv")
> head(DataSpecies)
  ID Species POINT_X POINT_Y PA
1  1 Lycaon pictus 32.16222 -21.49554 0
2  2 Lycaon pictus 31.40968 -21.10309 0
3  3 Lycaon pictus 31.46111 -21.86694 0
4  4 Lycaon pictus 31.31577 -21.65724 0
5  5 Lycaon pictus 32.32501 -22.09376 0
6  6 Lycaon pictus 31.96197 -21.39452 0
> myRespName <- 'PA'
> myResp <- as.numeric(DataSpecies[,myRespName])
> myRespXY <- DataSpecies[,c("POINT_X","POINT_Y")]
myExpl = stack("svcdistout.tif", "svcdistrivers.tif", "svcdi
stsett.tif", "svcelevation.tif", "svcveg.tif")
rgdal: version: 0.9-1, (SVN revision 518)
Geospatial Data Abstraction Library extensions to R
successfully loaded
Loaded GDAL runtime: GDAL 1.11.0, released
2014/04/16
Path to GDAL shared files: C:/Program Files/R/R-
3.1.0/library/rgdal/gdal
GDAL does not use iconv for recoding strings.

Loaded PROJ.4 runtime: Rel. 4.8.0, 6 March 2012,
[PJ_VERSION: 480]
Path to PROJ.4 shared files: C:/Program Files/R/R-
3.1.0/library/rgdal/proj
> myBiomodData <- BIOMOD
> myBiomodData <- BIOMOD_FormatingData(resp.var
= myResp,
+                                     expl.var = myExpl,
+                                     resp.xy = myRespXY,
+                                     resp.name = myRespName)
----- PA Data Formating -----
> No pseudo absences selection !
! No data has been set aside for modeling evaluatio
n
! Some NAs have be
en automatically removed from your data
----- Done -----
> myBiomodData
----- 'BIOMOD.formated.da
ta' -----
sp.name = PA
41014 presences, 21950 true absences an
d 0 undifined points in dataset
5 explanatory variables
svcdistout svcdistrivers svcdistsett svcelevatio
n svcveg
Min. : 0.000 Min. : 0 Min. : 0 483 :1024
1: 1639
1st Qu.: 0.000 1st Qu.: 2035 1st Qu.: 5189 464 :
971 2:25580
Median : 0.000 Median : 4196 Median : 8205 487
: 938 3: 9994
Mean : 7.904 Mean : 5074 Mean : 8456 486
: 931 4:22209
3rd Qu.: 0.000 3rd Qu.: 7339 3rd Qu.:11869 481
: 914 5: 3542
Max. :1017.733 Max. :19761 Max. :18347 484
: 896
(Other):57290
-----
> plot(myBiomodData)
Loading required package: rasterVis
Loading required package: lattice
Loading required package: latticeExtra
Loading required package: RColorBrewer
Loading required package: hexbin
Warning messages:
1: package 'rasterVis' was built under R version 3.1.2
2: package 'latticeExtra' was built under R version
3.1.2

```

```

3: package 'RColorBrewer' was built under R version
3.1.2
4: package 'hexbin' was built under R version 3.1.2
> myBiomodOption <- BIOMOD_ModelingOptions()
> myBiomodOption
-----
'BIOMOD.Model.Options' -----
===
GLM = list( type = 'quadratic',
  interaction.level = 0,
  myFormula = NULL,
  test = 'AIC',
  family = binomial(link = 'logit'),
  mustart = 0.5,
  control = glm.control(epsilon = 1e-08, maxit =
50, trace = FALSE) ),
GBM = list( distribution = 'bernoulli',
  n.trees = 2500,
  interaction.depth = 7,
  n.minobsinnode = 5,
  shrinkage = 0.001,
  bag.fraction = 0.5,
  train.fraction = 1,
  cv.folds = 3,
  keep.data = FALSE,
  verbose = FALSE,
  perf.method = 'cv'),
GAM = list( algo = 'GAM_mgcv',
  type = 's_smoother',
  k = -1,
  interaction.level = 0,
  myFormula = NULL,
  family = binomial(link = 'logit'),
  method = 'GCV.Cp',
  optimizer = c('outer','newton'),
  select = FALSE,
  knots = NULL,
  paraPen = NULL,
  control = list(nthreads = 1, irls.reg = 0, epsilon =
1e-07, maxit = 100
, trace = FALSE, mgcv.tol = 1e-07, mgcv.half = 15,
rank.tol = 1.49011611938477e-08
, nlm = list(ndigit=7, gradtol=1e-06, stepmax=2,
steptol=1e-04, iterlim=200, check.analyticals=0)
, optim = list(factr=1e+07)
, newton = list(conv.tol=1e-06, maxNstep=5,
maxSstep=2, maxHalf=30, use.svd=0)
, outerPlsteps = 0, idLinksBases = TRUE, scalePenalty =
TRUE, keepData = FALSE) ),
MAXENT = list( path_to_maxent.jar =
'C:/BIOMODMSC',
  memory_allocated = 512,
  maximumiterations = 200,
  visible = FALSE,
  linear = TRUE,
  quadratic = TRUE,
  product = TRUE,
  threshold = TRUE,

```

```

  hinge = TRUE,
  lq2lqptthreshold = 80,
  l2lqthreshold = 10,
  hingethreshold = 15,
  beta_threshold = -1,
  beta_categorical = -1,
  beta_lqp = -1,
  beta_hinge = -1,
  defaultprevalence = 0.5)
-----
> myBiomodModelOut <- BIOMOD_Modeling(
+ myBiomodData,
+ models = c('GLM','GAM','MAXENT'),
+ models.options = myBiomodOption,
+ NbRunEval=15,
+ DataSplit=75,
+ Prevalence=0.5,
+ VarImport=3,
+ models.eval.meth = c('KAPPA','ROC'),
+ SaveObj = TRUE,
+ rescal.all.models = TRUE,
+ do.full.models = FALSE,
+ modeling.id =
paste(myRespName,"FirstModeling",sep=""))
Loading required library...
Checking Models arguments...
Creating suitable Workdir...
  > Automatic weights creation to rise a 0.5
prevalence
----- PA Modeling
Summary -----
5 environmental variables ( svcdistout svcdistrivers
svcdistsett svcelevation svcveg)
Number of evaluation repetitions : 15
Models selected : GLM GAM MAXENT
Total number of model runs : 45
-----
-----
----- Run : PA_AllData
----- PA_AllData_RUN1*15
Model=GLM quadratic with no interaction
  Stepwise procedure using AIC criteria
  selected formula : PA ~ I(svcdistout^2) +
svcdistrivers + svcdistout + svcdistsett
+svcelevation+svcveg
  I(svcdistsett^2) + I(svcdistrivers^2)+
I(svcelevation^2)+ I(svcveg^2)
<environment: 0x00000001bd91e98>
  Model scaling...
  Evaluating Model stuff...
  Evaluating Predictor Contributions...
Model=GAM
  GAM_mgcv algorithm chosen
Attaching package: 'nlme'
The following object is masked from 'package:raster':
  getData

```

This is mgcv 1.7-29. For overview type 'help("mgcv-package")'.

```

Automatic formula generation...
> GAM (mgcv) modelling...
Model scaling...
Evaluating Model stuff...
Evaluating Predictor Contributions...
MAXENT defaultprevalence option was
updated to fit with modeling prevalence (i.e 0.5 )
Model=MAXENT
Creating Maxent Temp Proj Data..
Running Maxent...
Getting predictions...
Removing Maxent Temp Data..
Model scaling...
Evaluating Model stuff...
Evaluating Predictor Contributions...
----- Done -----
=====
Warning message:
running command 'java' had status 1
> myBiomodModelOut
=====
BIOMOD.models.out -----
=
Modeling id : PAFirstModeling
Species modeled : PA
Considered variables : svcdistout svcdistrivers
svcdistsett
Computed Models : PA_AllData_RUN1_GLM
PA_AllData_RUN1_GAM PA_AllData_RUN1_MAXENT
PA_AllData_RUN2_GLM PA_AllData_RUN2_GAM
PA_AllData_RUN2_MAXENT PA_AllData_RUN3_GLM

```

```

PA_AllData_RUN3_GAM PA_AllData_RUN3_MAXENT
Failed Models : none
-----
-----
> myBiomodModelEval <-
get_evaluations(myBiomodModelOut)
> dimnames(myBiomodModelEval)
[[1]]
[1] "KAPPA" "ROC"
[[2]]
[1] "Testing.data" "Cutoff" "Sensitivity"
"Specificity"
[[3]]
[1] "GLM" "GAM" "MAXENT"
[[4]]
[1] "RUN1" "RUN2" "RUN3"....."RUN15"
[[5]]
PA_AllData
"AllData"
> myBiomodModelEval["ROC", "Testing.data",,,,]
RUN1...15 avg
GLM 0.860
GAM 0.885
MAXENT 0.895
> get_variables_importance(myBiomodModelOut)
, , RUN1.....15, AllData
GLM GAM MAXENT
svcdistout 0.977 0.596 0.754
svcdistrivers 0.000 0.139 0.068
svcdistsett 0.140 0.327 0.095
svcelevation
svcveg

```


APPENDIX C: ADDITIONAL T-LOCOH GEOGRAPHICAL AND TEMPORAL DISTRIBUTIONS WILD DOG PACKS

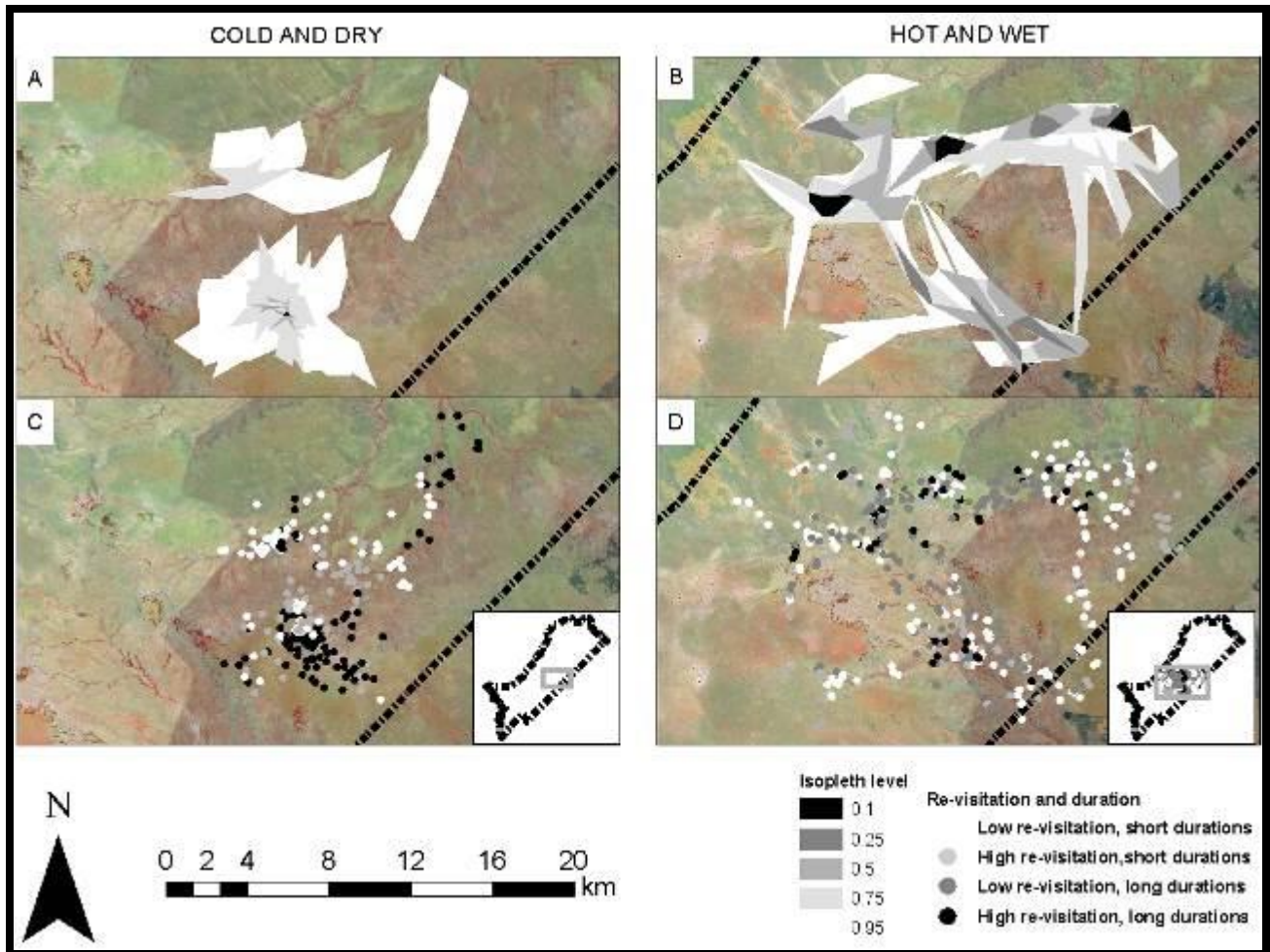


Figure C. 1 Isopleths for the cold and dry season (A) and the hot and wet season (B) as well as re-visitation rates and durations of stay for the cold and dry season (C) and the hot and wet season (D) for Chalanda in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

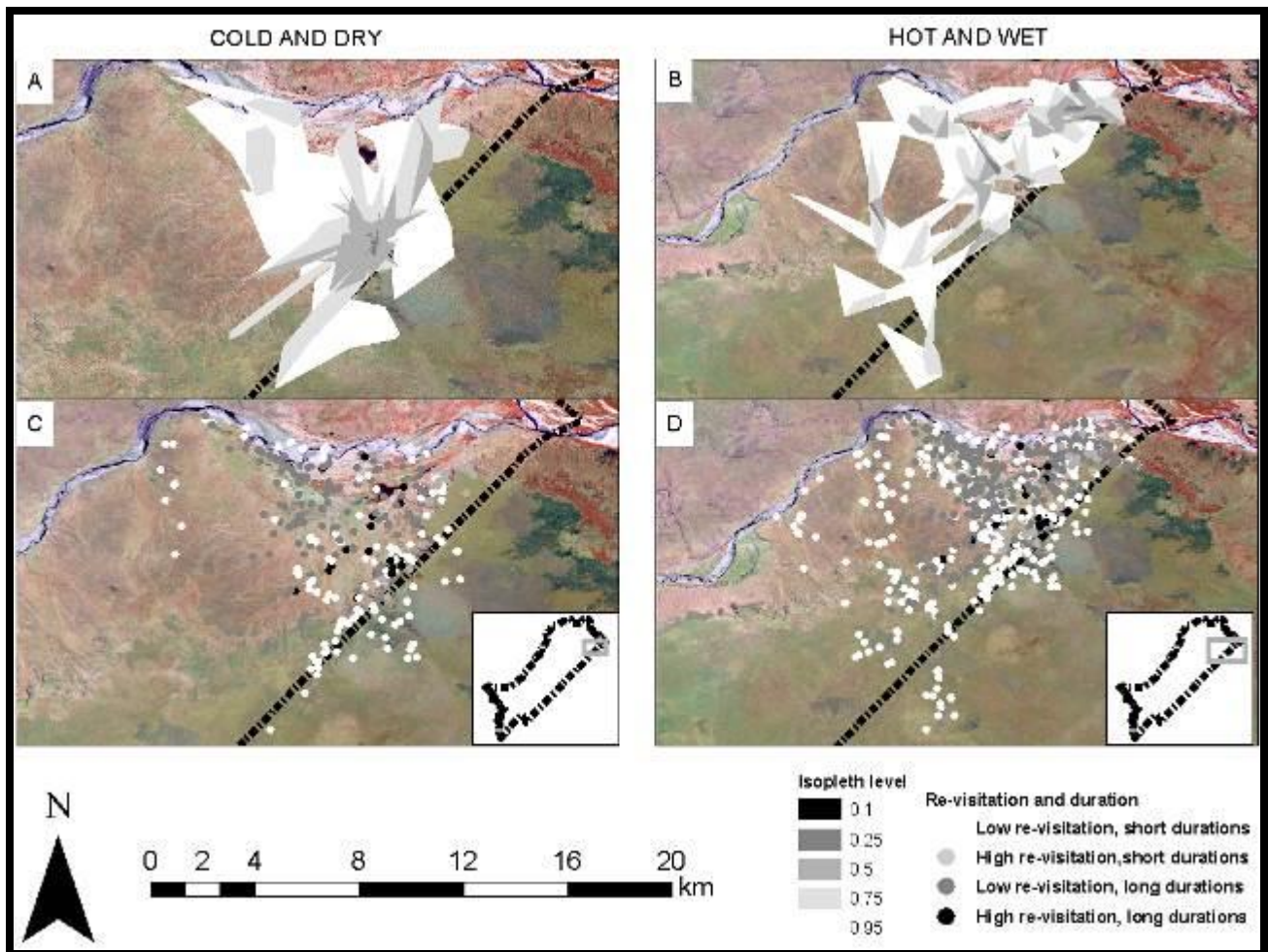


Figure C. 2 Isopleths for the cold and dry season (A) and the hot and wet season (B) as well as re-visitation rates and durations of stay for the cold and dry season (C) and the hot and wet season (D) for Machaniwa in GNP. Background image is Landsat 8, band combination 5-6-4, stretch: percent clip with min and max of 0.25

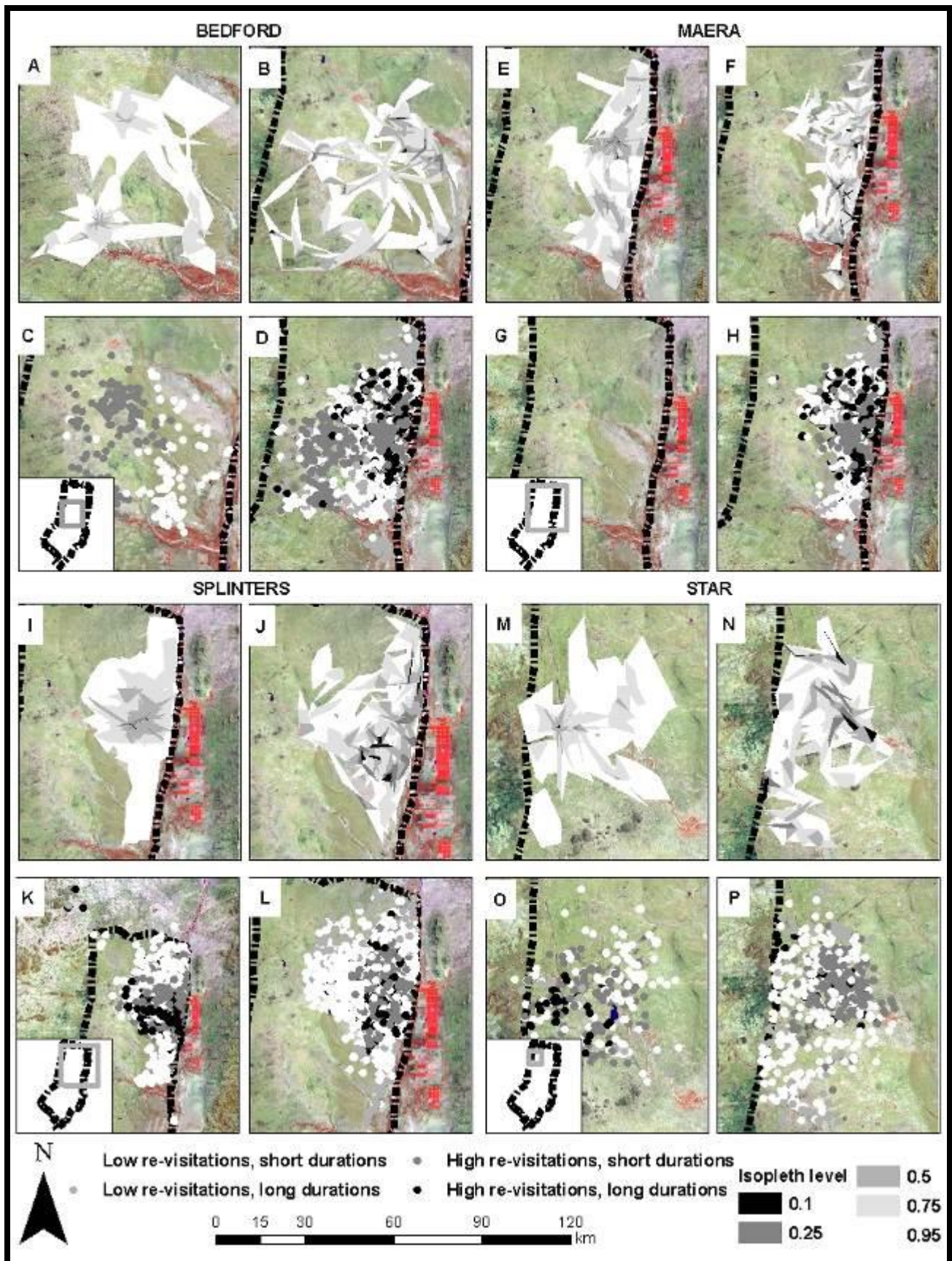


Figure C. 3 Bedford, Maera, Splinters and Star packs from SVC's packs where A,E, C,G,I,K, M,O represent the cold and dry season and B,F,D,H,J,N,L,P is the hot and wet season. Background image is Landsat 8 band combination 5-6-4, stretch: percent clip with min and max of 0.25

APPENDIX D: WILD DOG RE-VISITATION RATES AND DURATION OF STAY PLOTTED USING ISOPLETHS COLOUR CODE AND CORRESPONDING MAPS IN DIFFERENT SEASONS

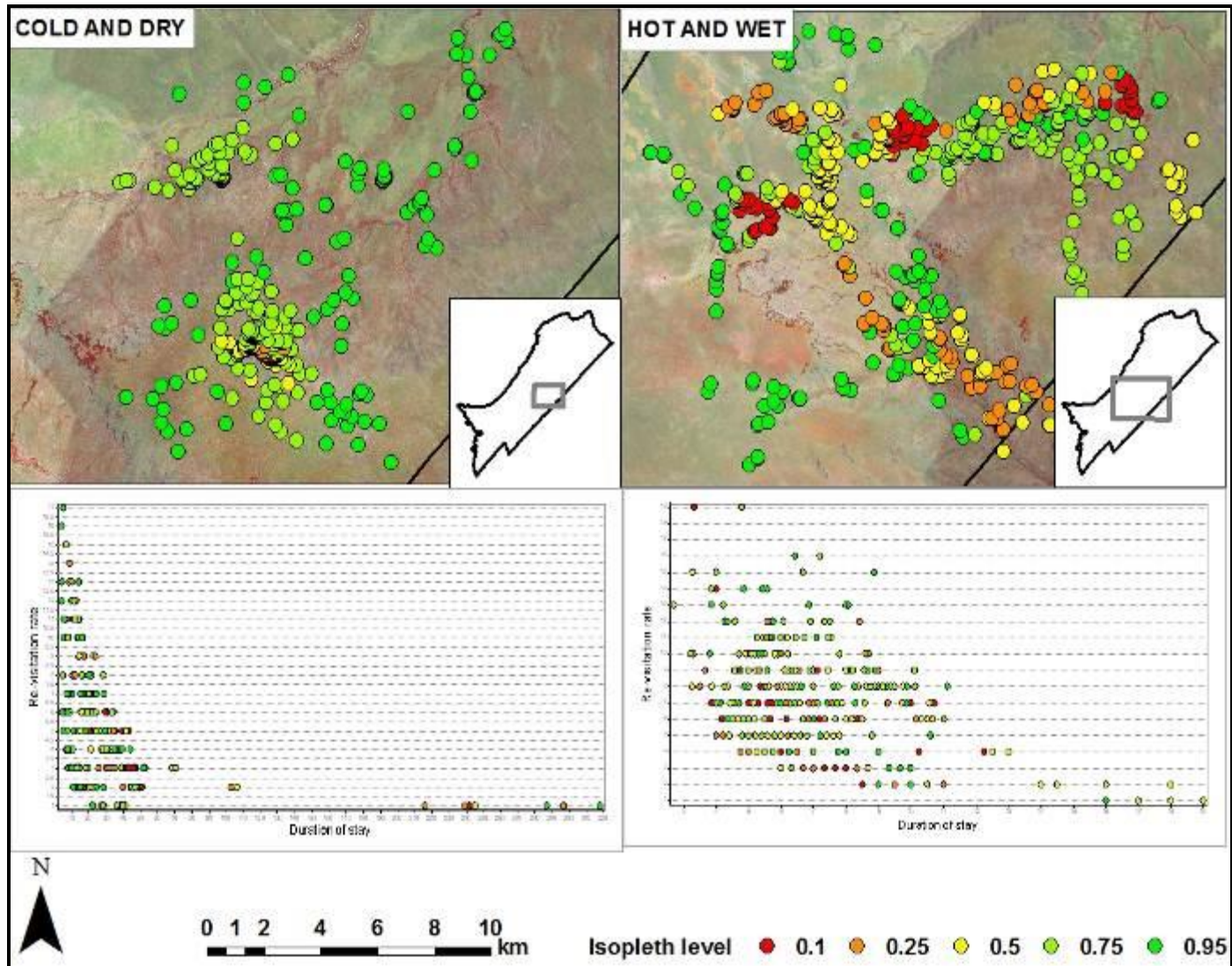


Figure D. 1 Chalanda plot of re-visitation against duration of stay using isopleths levels for colour coding

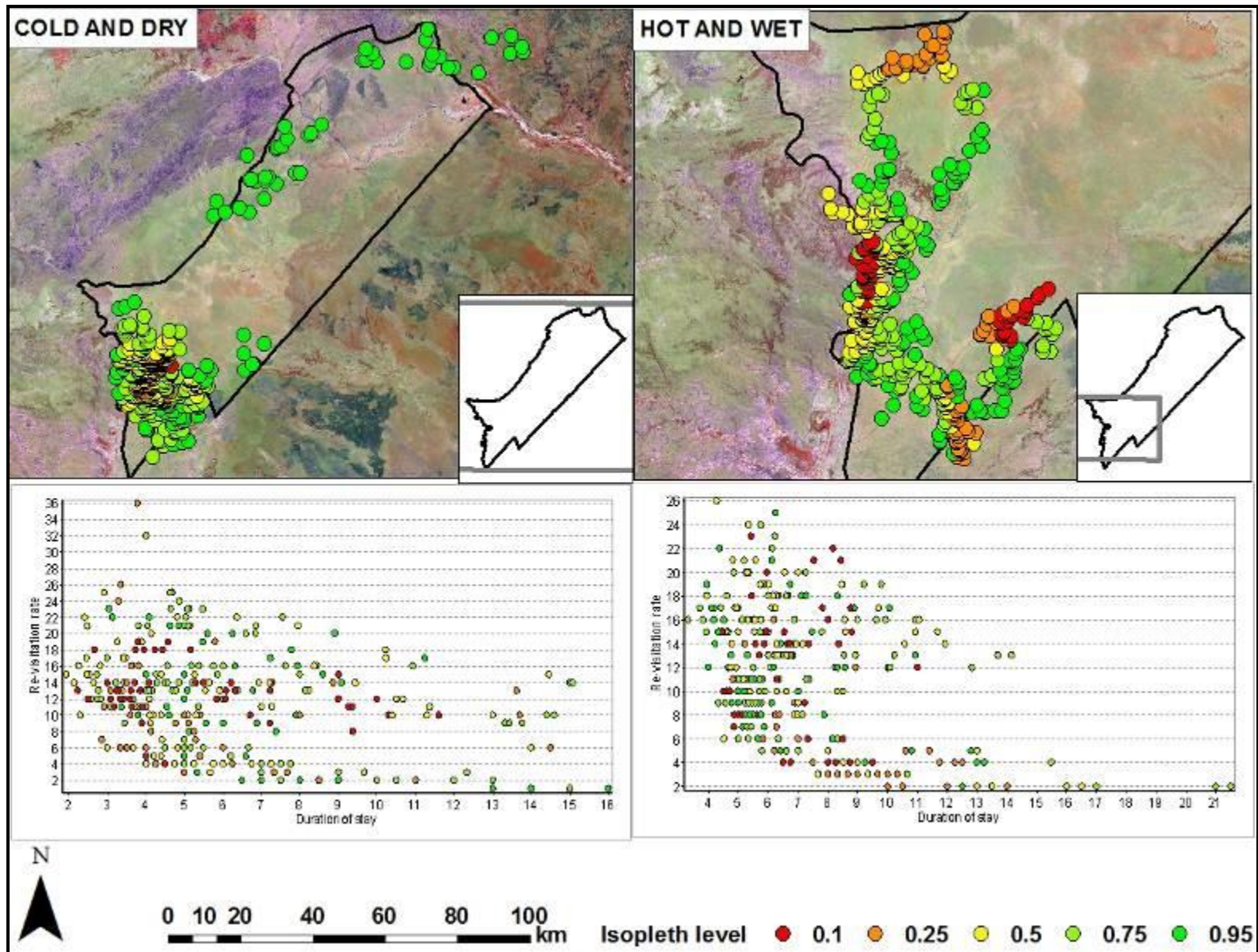


Figure D. 2 Mabalauta plot of re-visitation against duration of stay using isopleths levels for colour coding

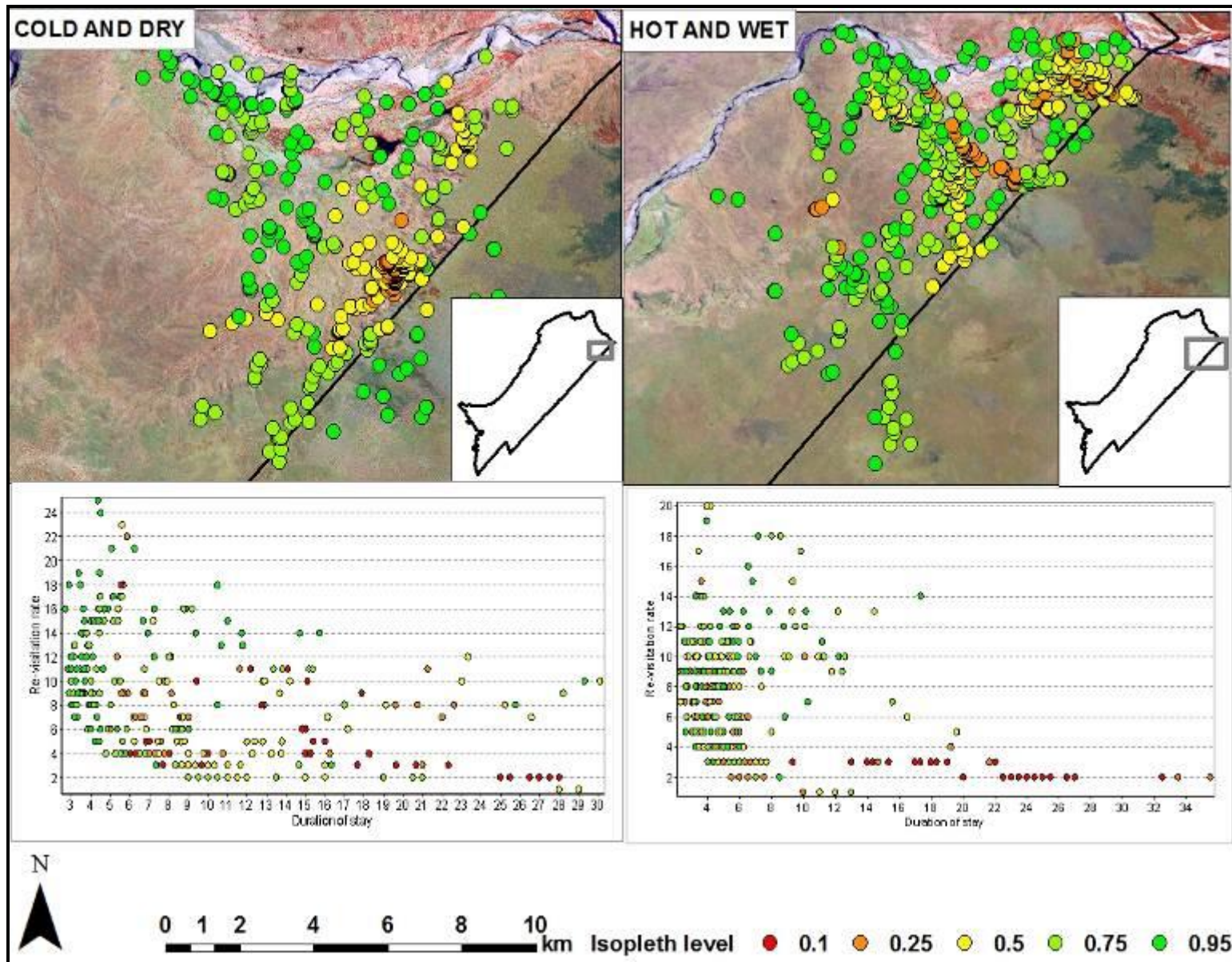


Figure D. 3 Machaniwa plot of re-visitation against duration of stay using isopleths levels for colour coding

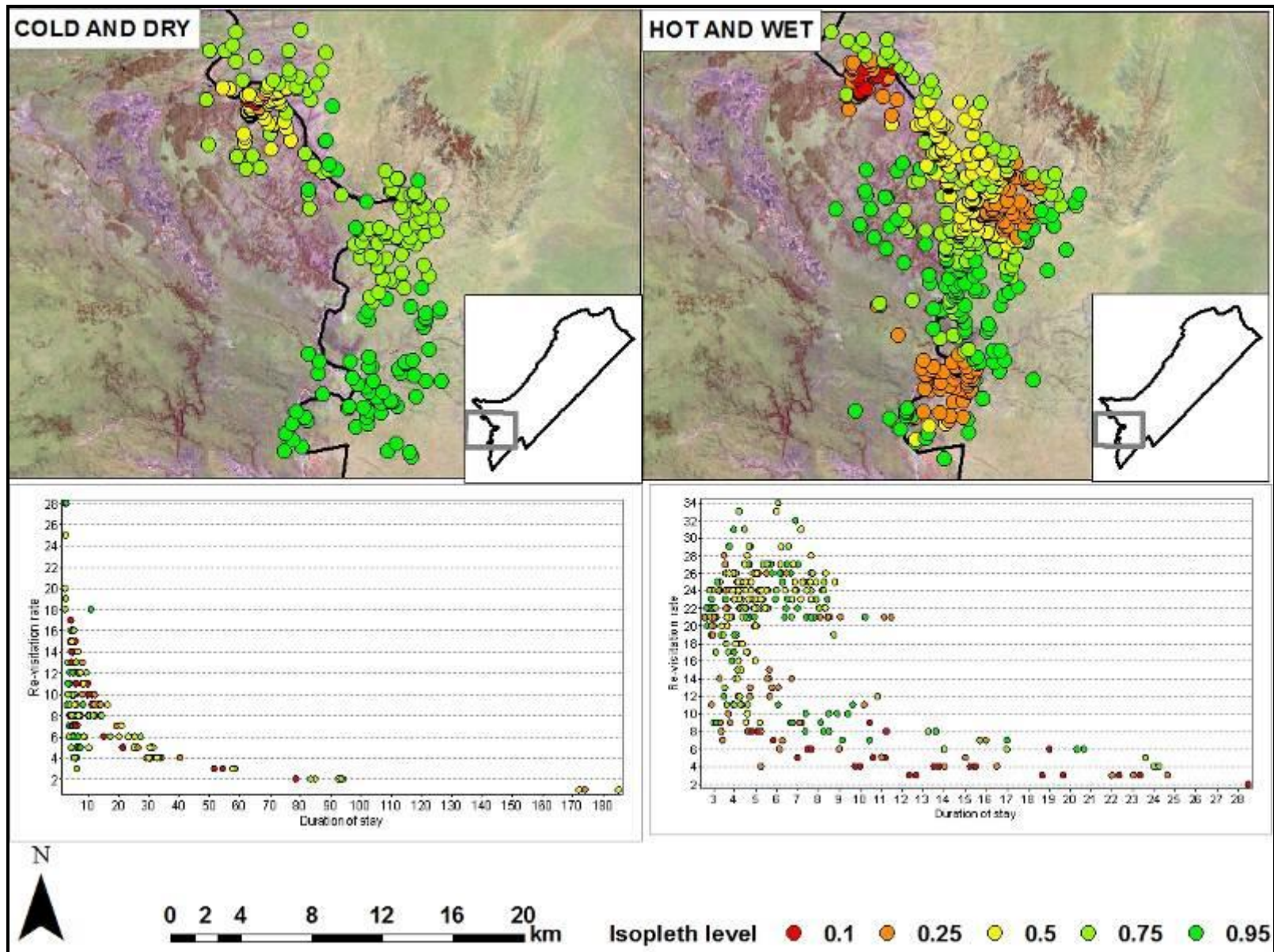


Figure D. 4 Shangana plot of re-visitation against duration of stay using isopleth levels for colour coding

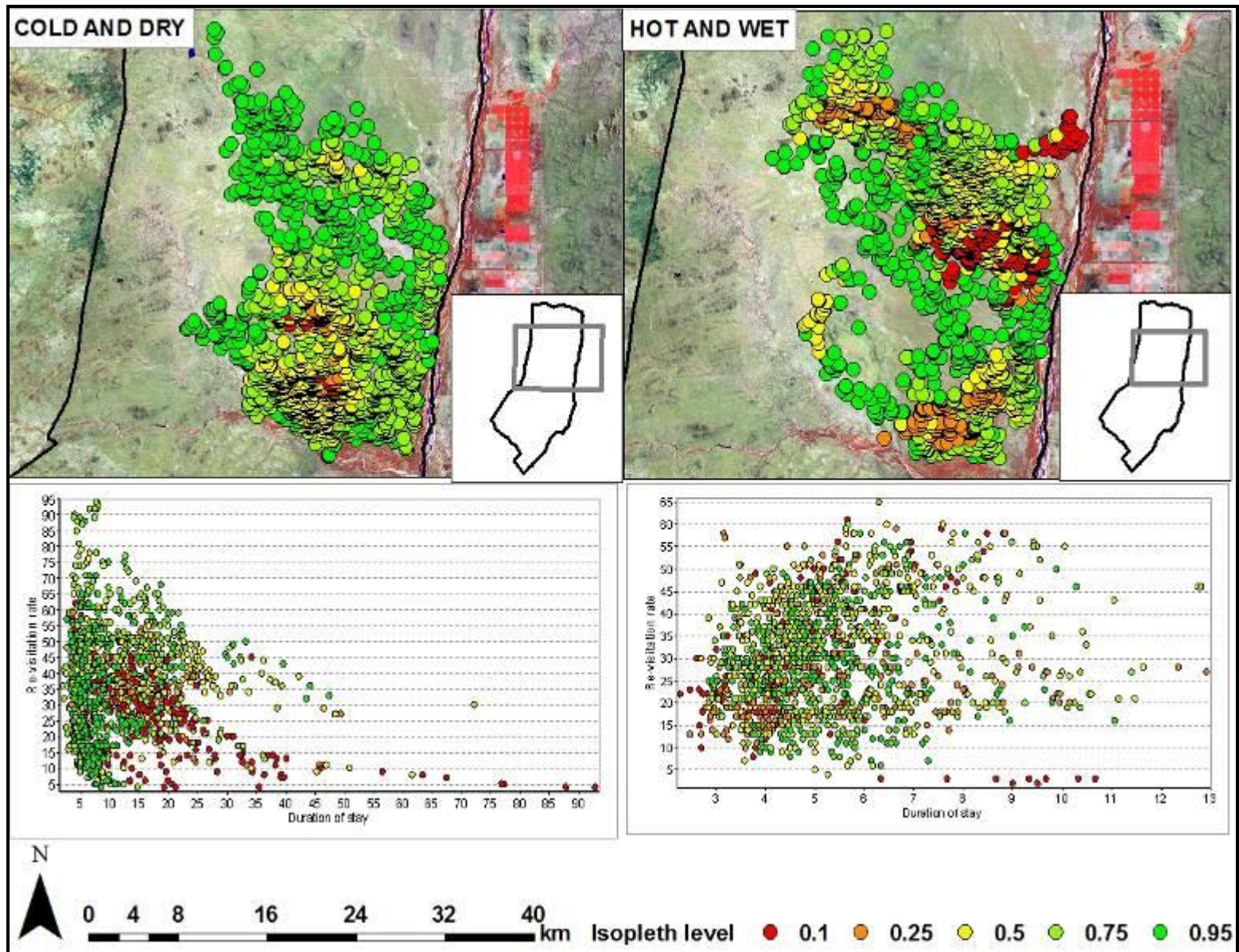


Figure D. 5 Batanai plot of re-visitation against duration of stay using isopleths levels for colour coding

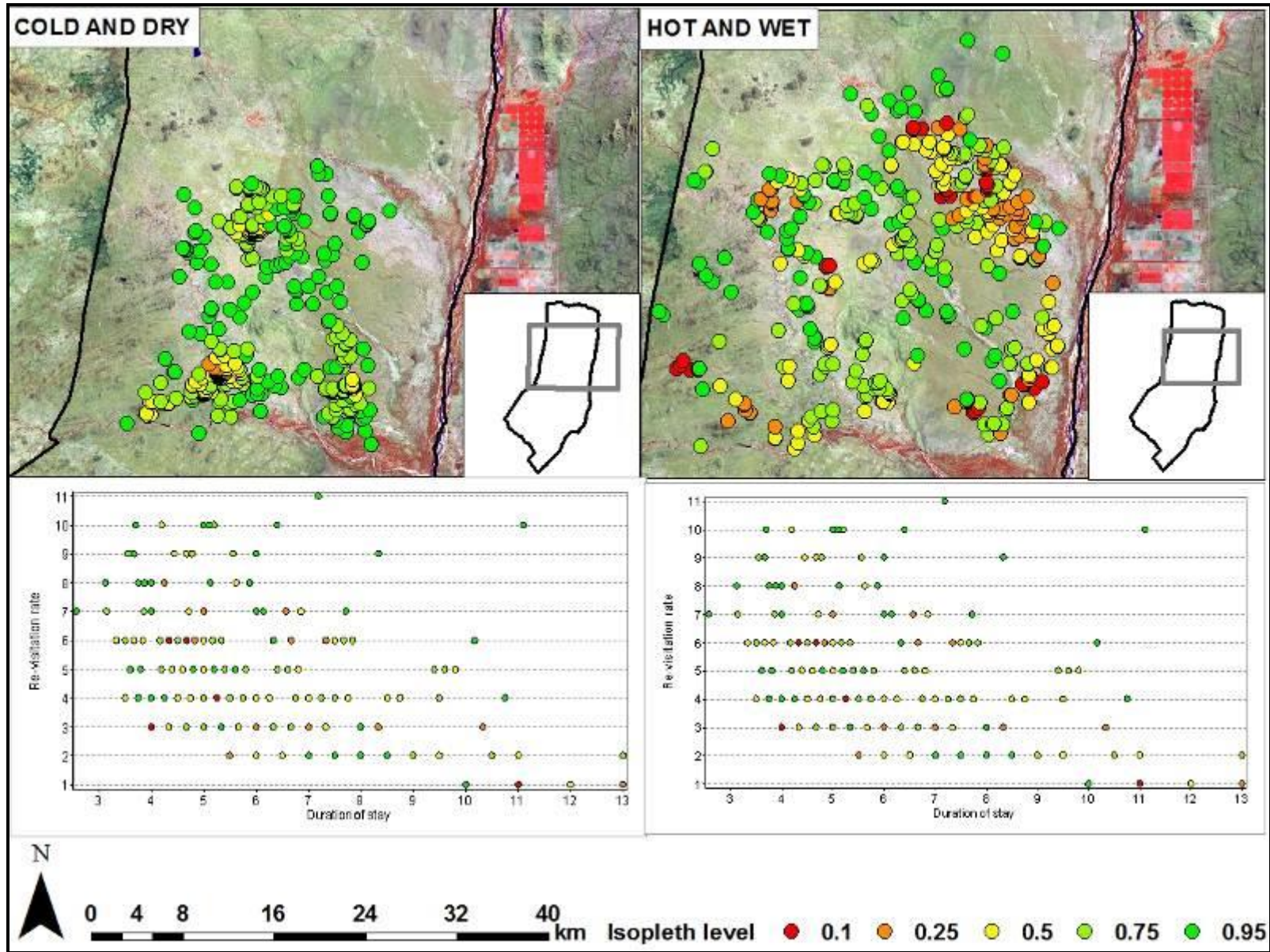


Figure D. 6 Bedford plot of re-visitation against duration of stay using isopleth levels for colour coding

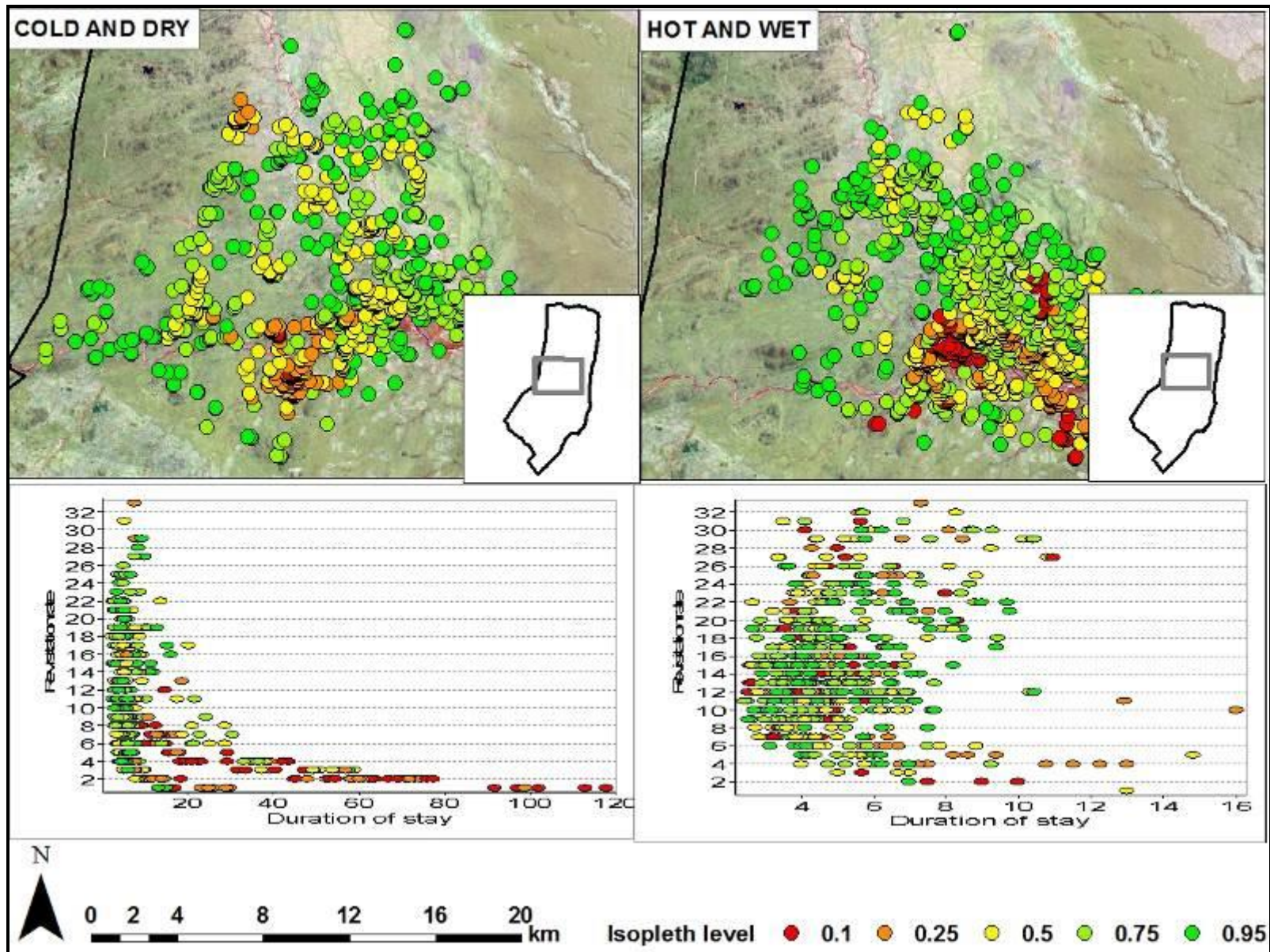


Figure D. 7 Crocodile plot of re-visitation against duration of stay using isopleth levels for colour coding

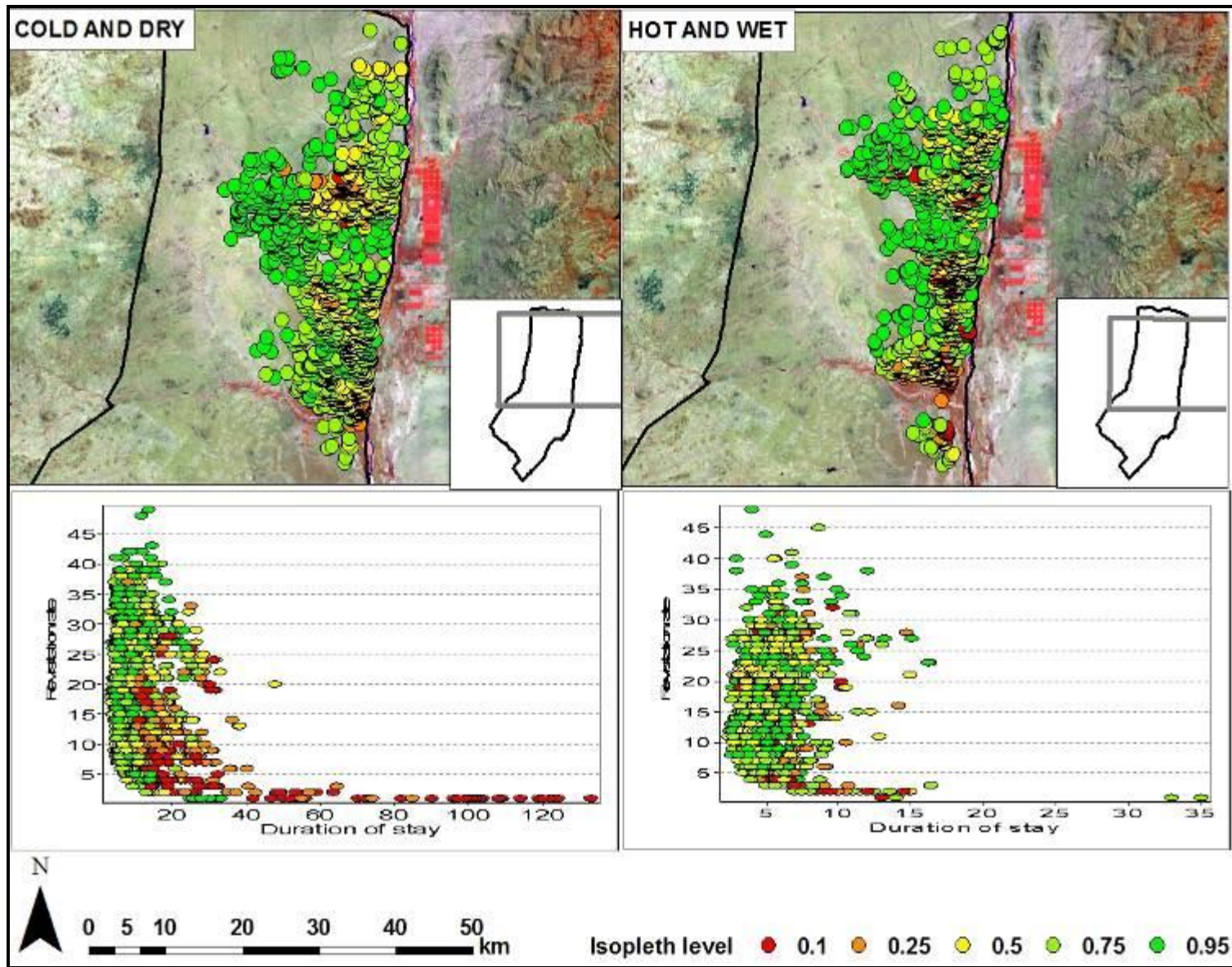


Figure D. 8 Maera plot of re-visitation against duration of stay using isopleths levels for colour coding

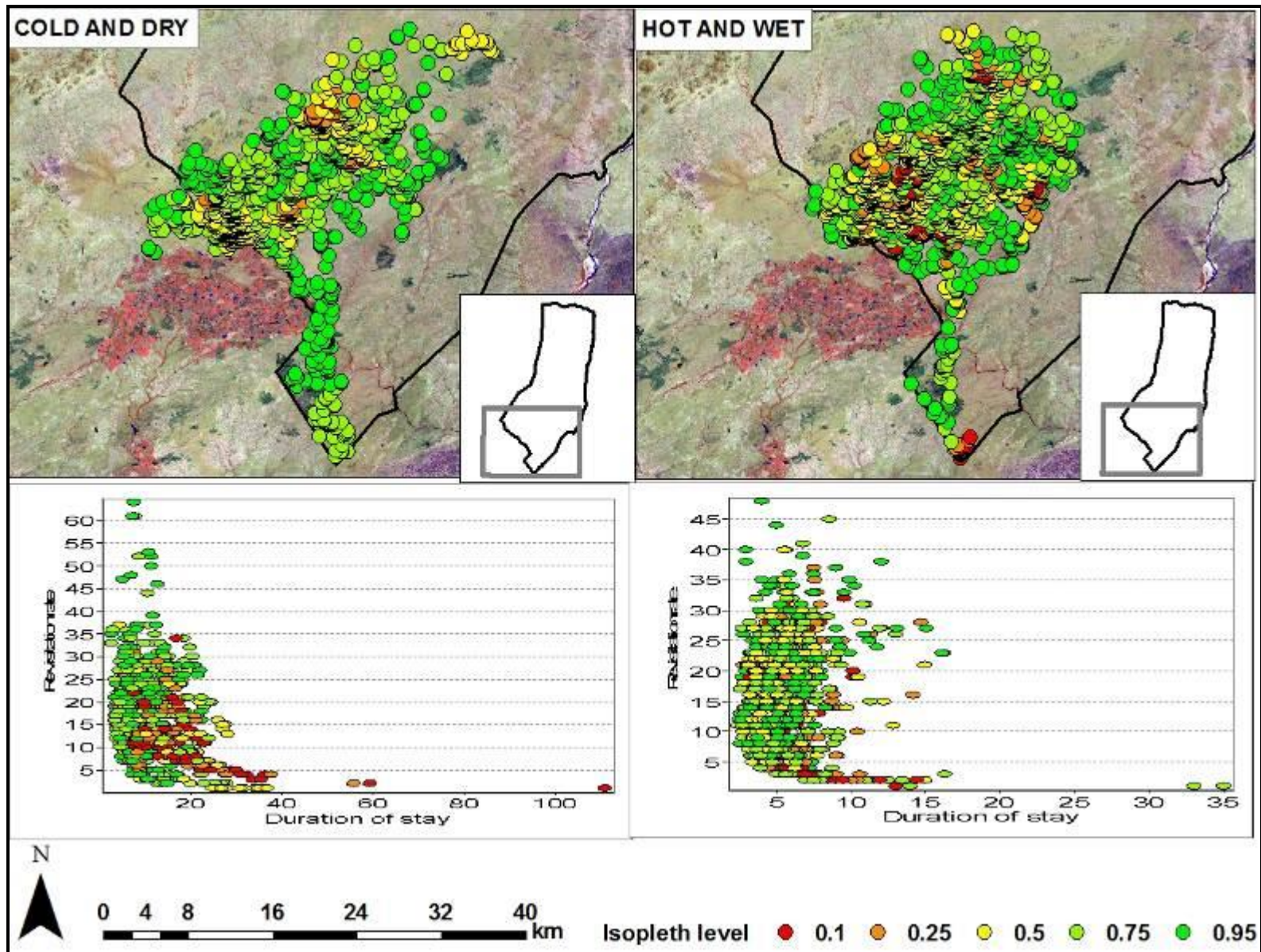


Figure D. 9 Mambira plot of re-visitation against duration of stay using isopleths levels for colour coding

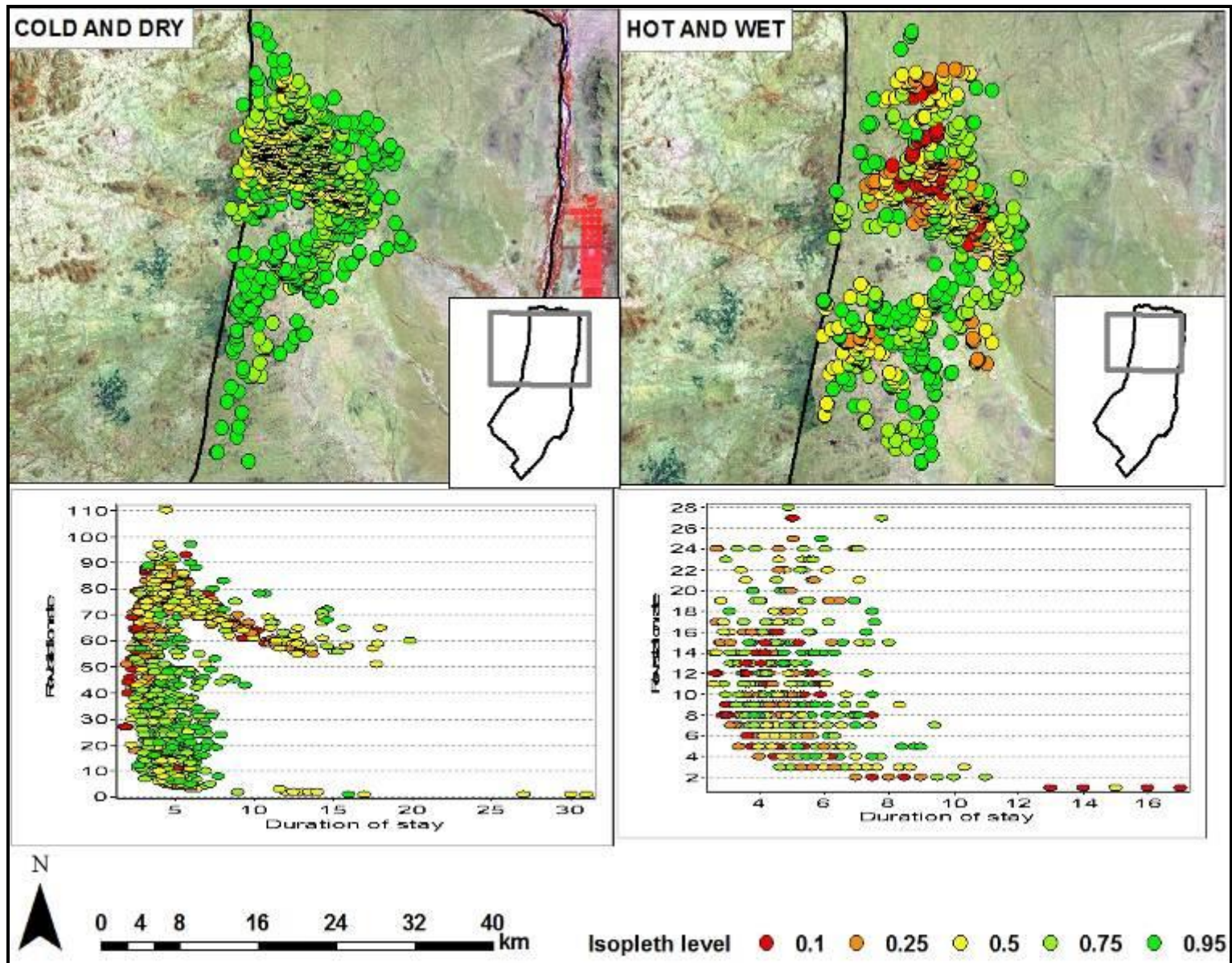


Figure D. 10 Mapura plot of re-visitation against duration of stay using isopleths levels for colour coding

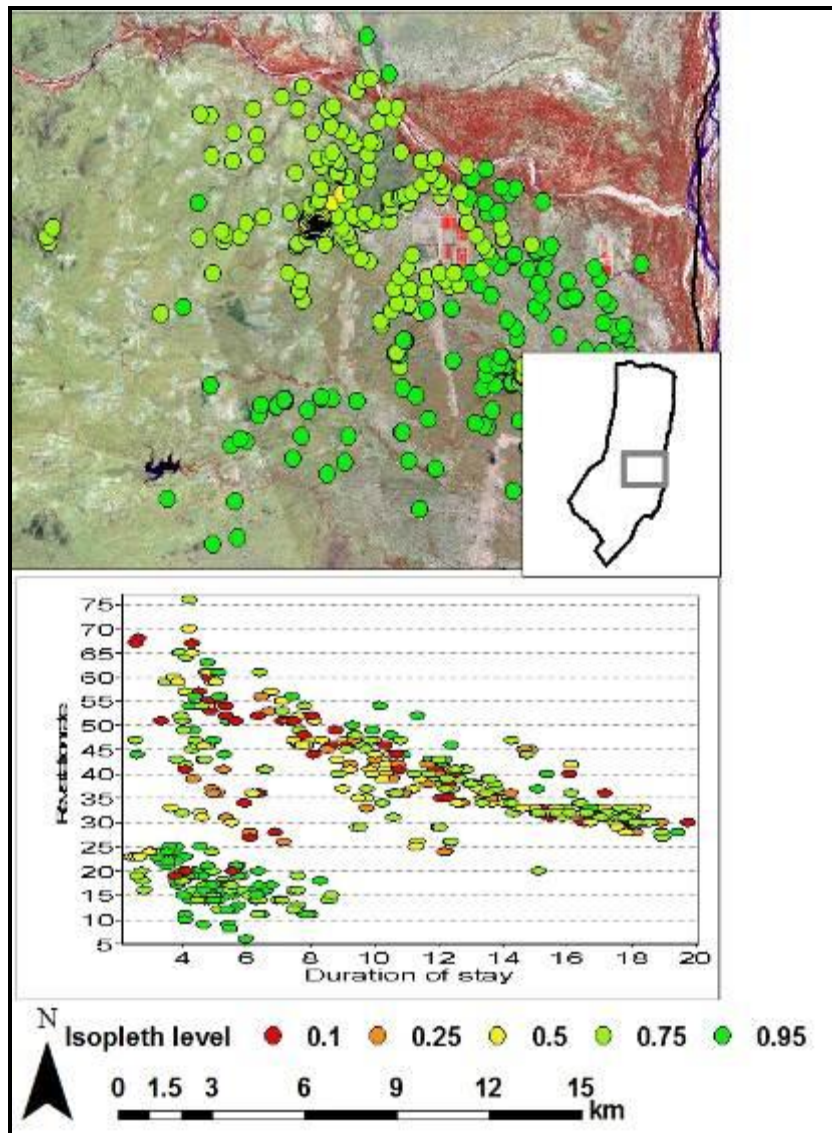


Figure D. 11 Nyarushanga plot of re-visitation against duration of stay using isopleths levels for colour coding

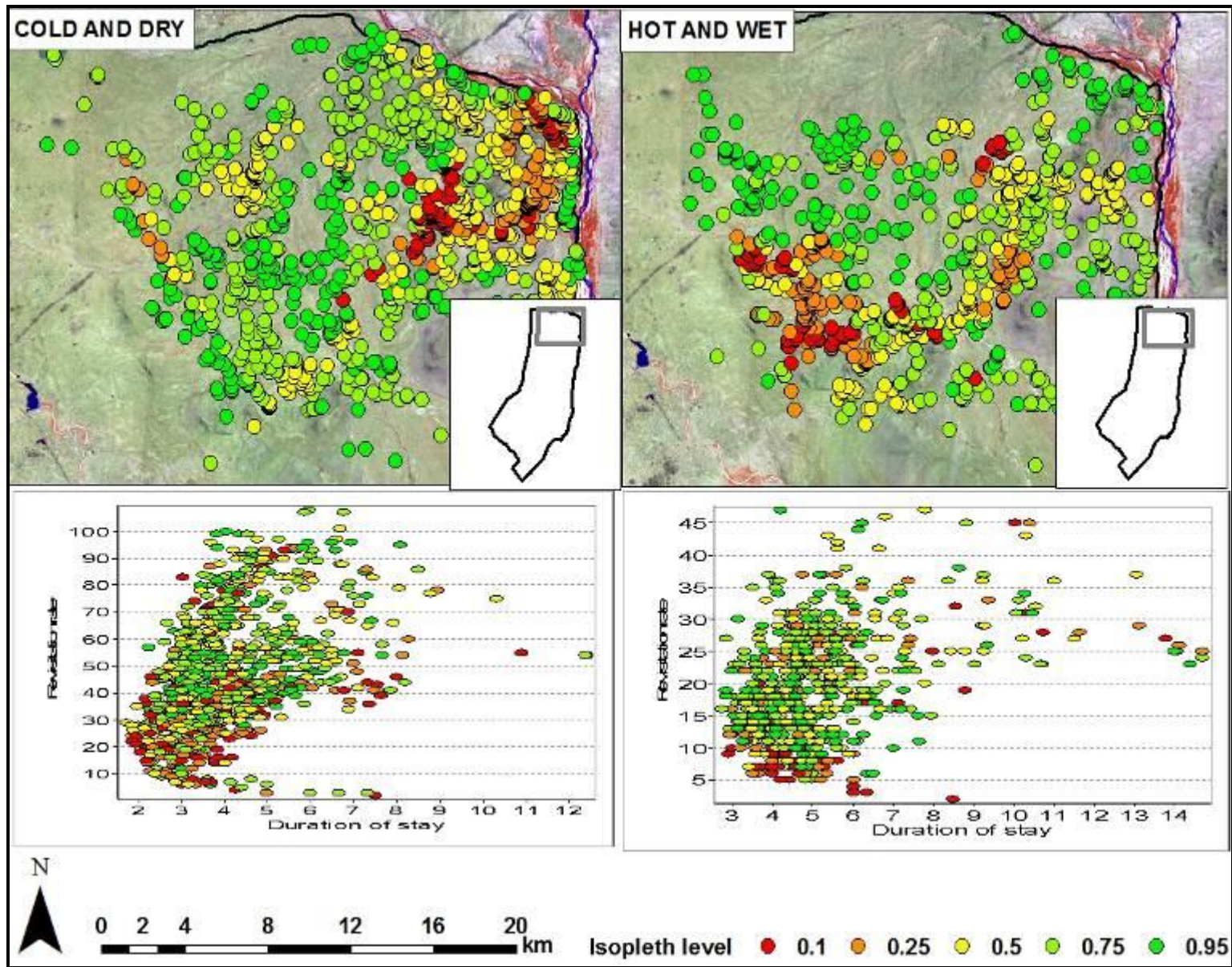


Figure D. 12 Patch plot of re-visitation against duration of stay using isopleths levels for colour coding

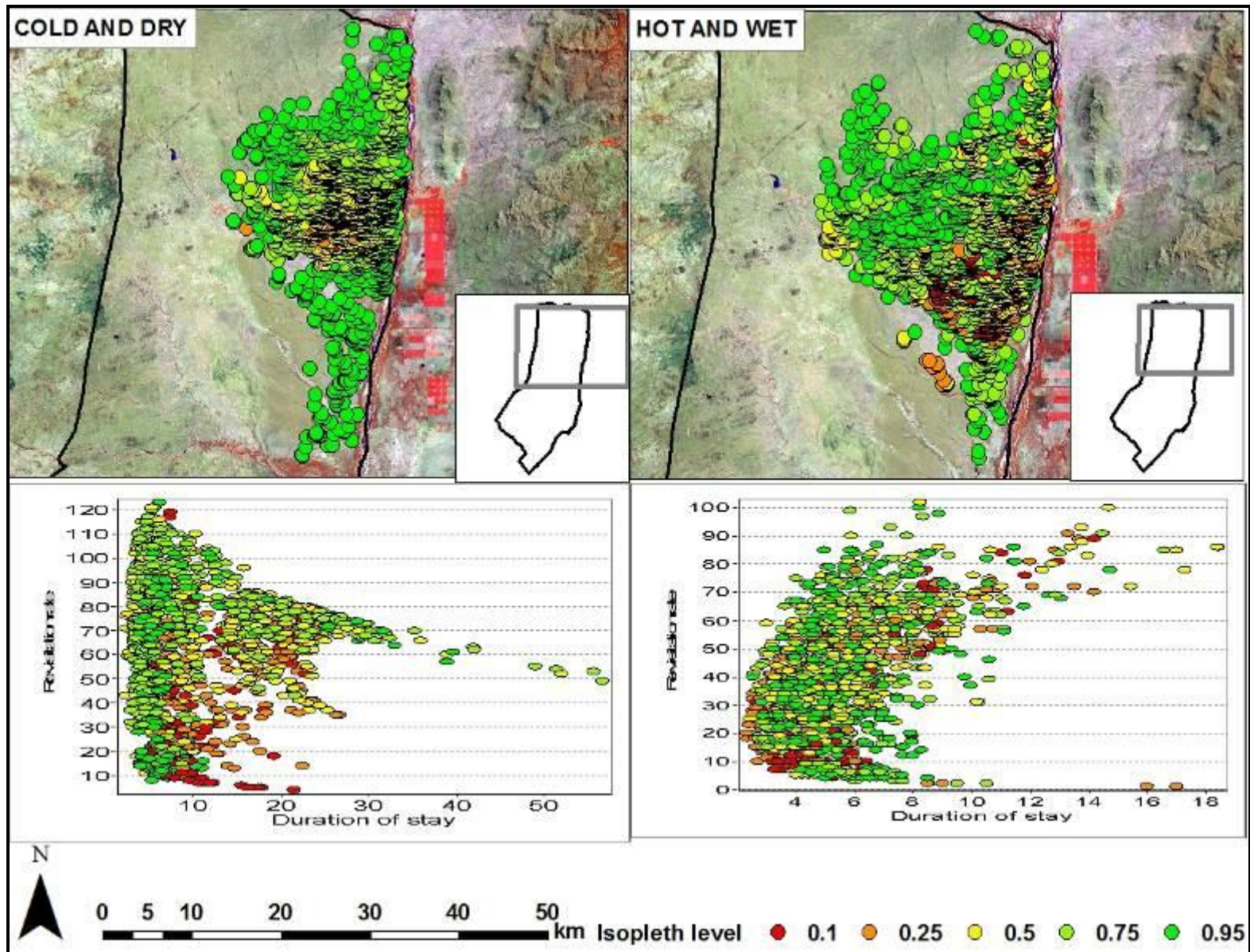


Figure D. 13 Splinters plot of re-visitation against duration of stay using isopleths levels for colour coding

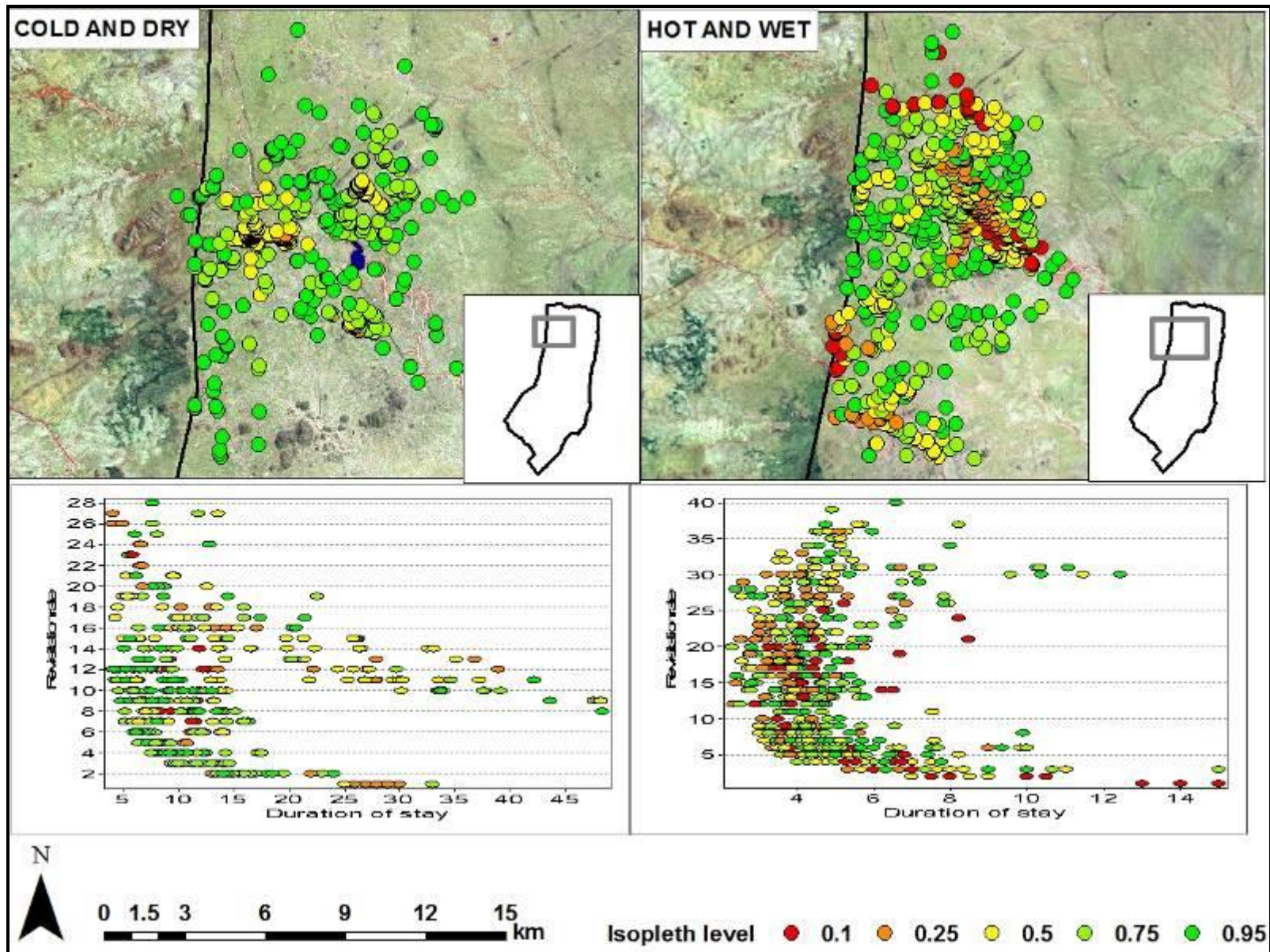


Figure D. 14 Star plot of re-visitation against duration of stay using isopleths levels for colour coding

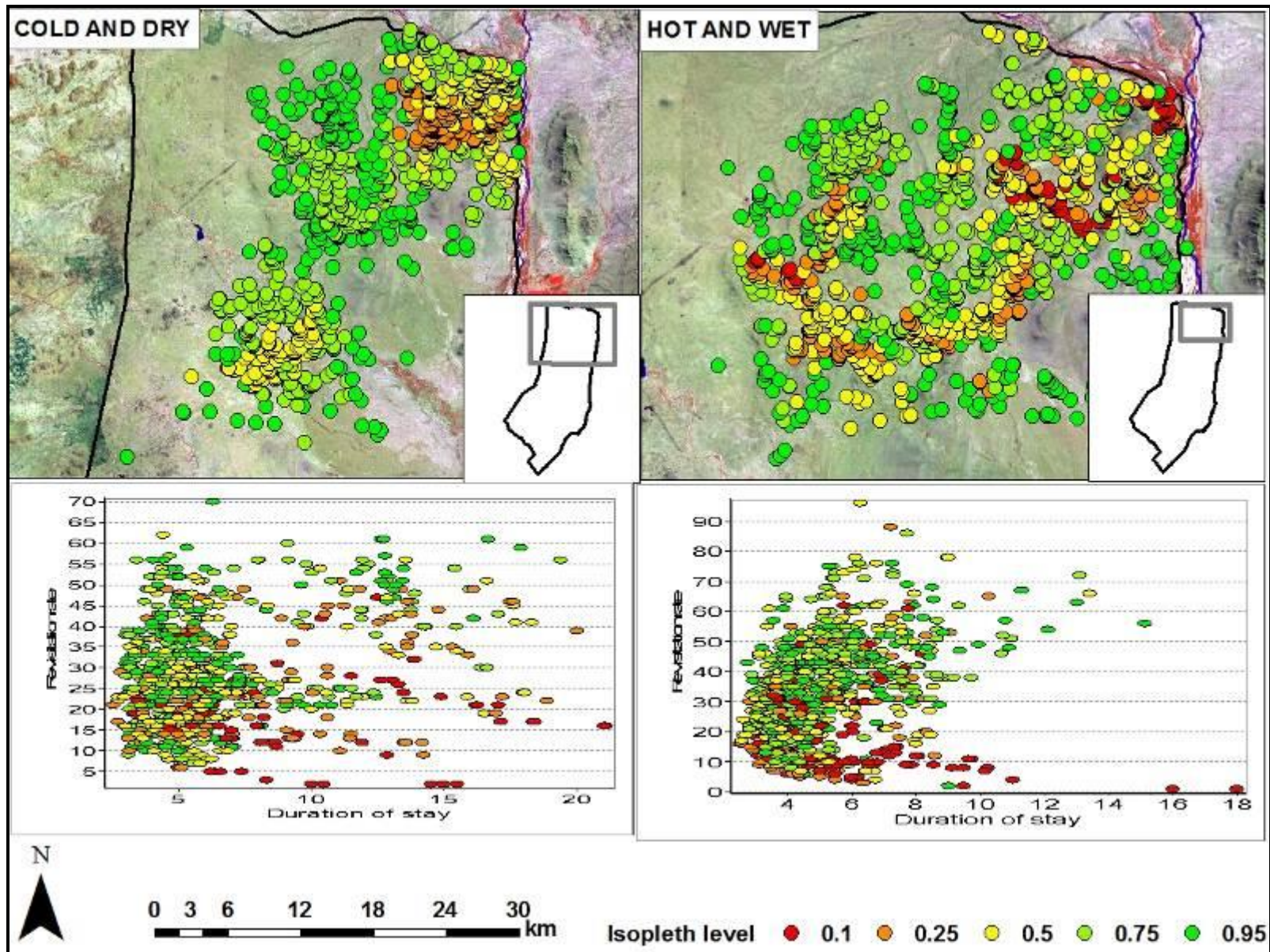


Figure D. 15 Tick plot of re-visitation against duration of stay using isopleths levels for colour coding

APPENDIX E: MAXENT RESPONSE CURVES RESULTS PER PACK

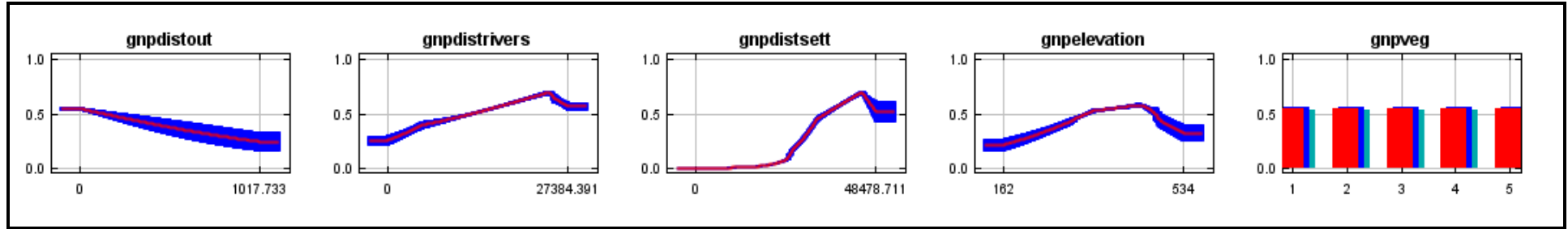


Figure E. 1 Chalanda response curves

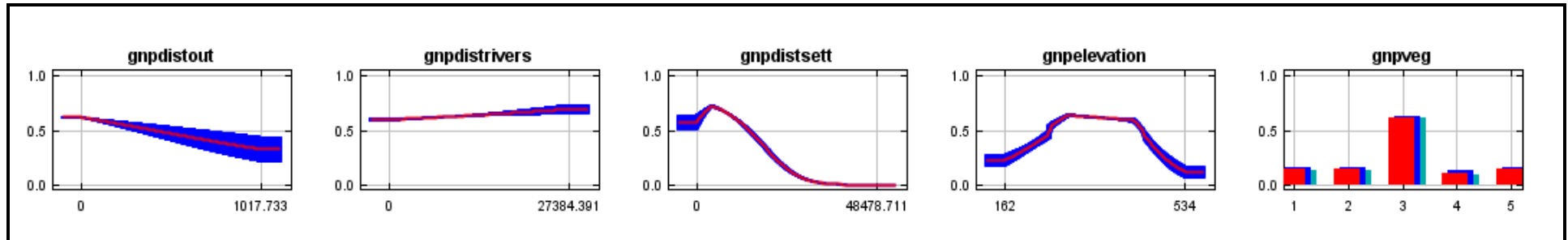


Figure E. 2 Mabaluta response curves

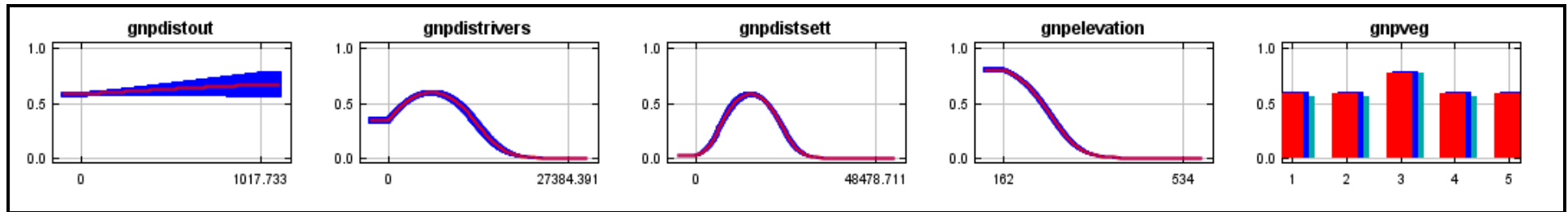


Figure E. 3 Machaniwa response curves

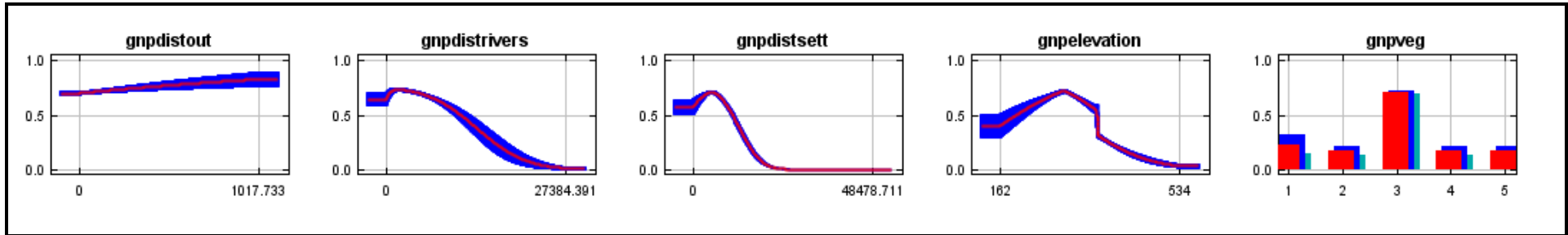


Figure E. 4 Shangana response curves

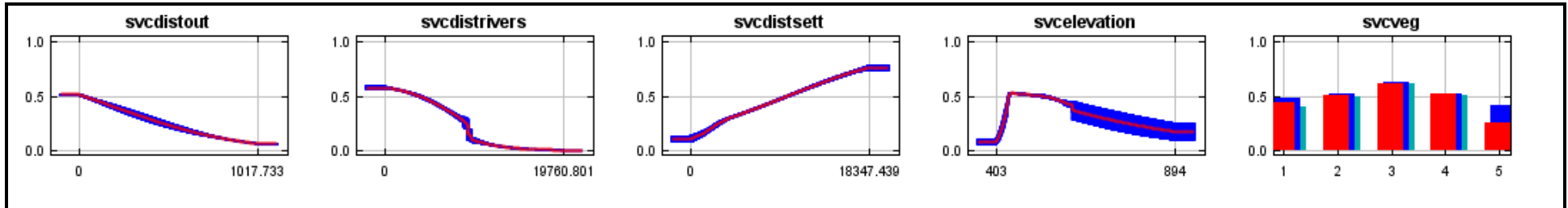


Figure E. 5 Batanai response curves

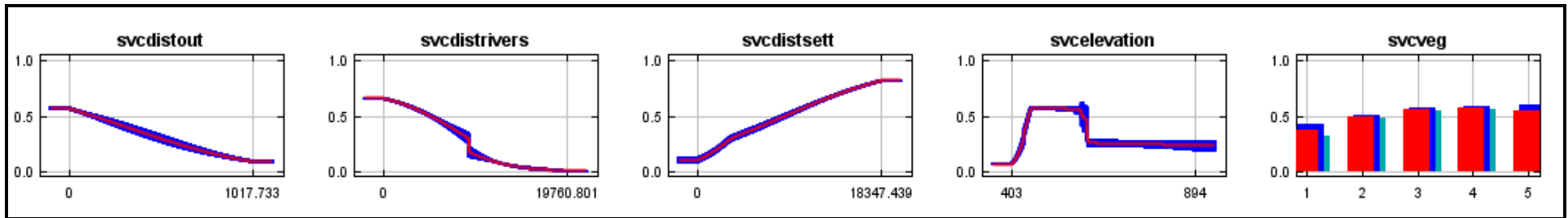


Figure E. 6 Bedford response curves

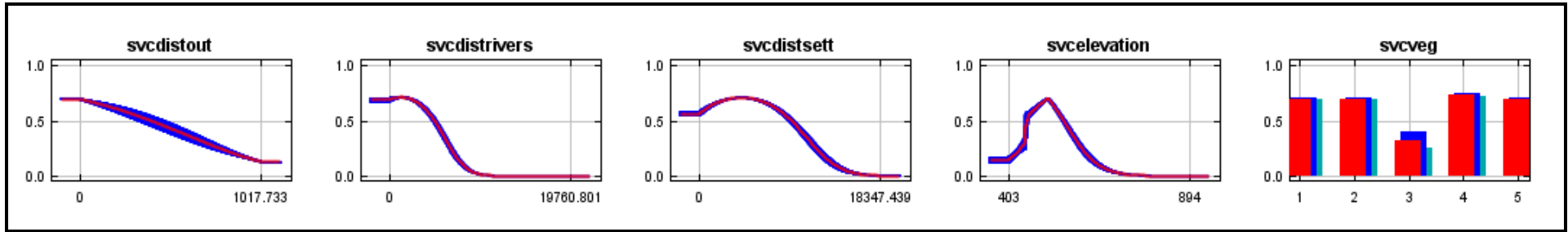


Figure E. 7 Crocodile response curves

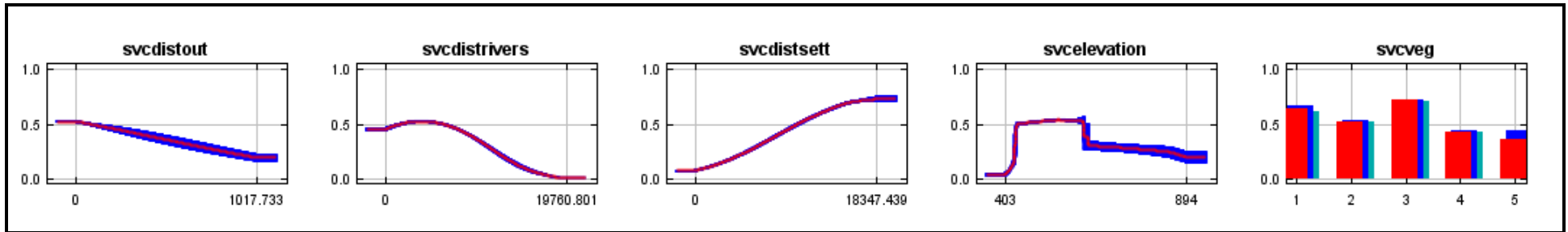


Figure E. 8 Maera response curves

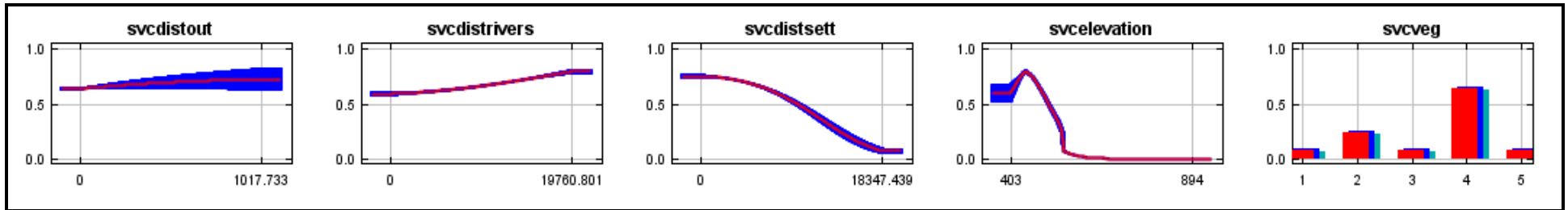


Figure E. 9 Mambira response curves

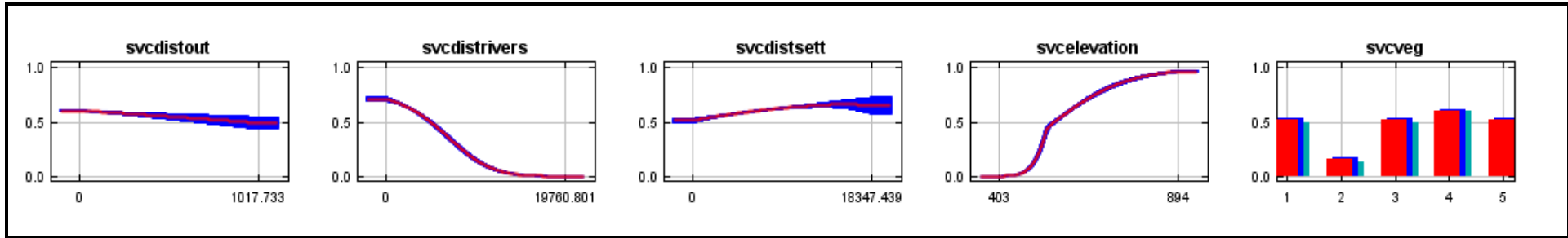


Figure E. 10 Mapura response curves

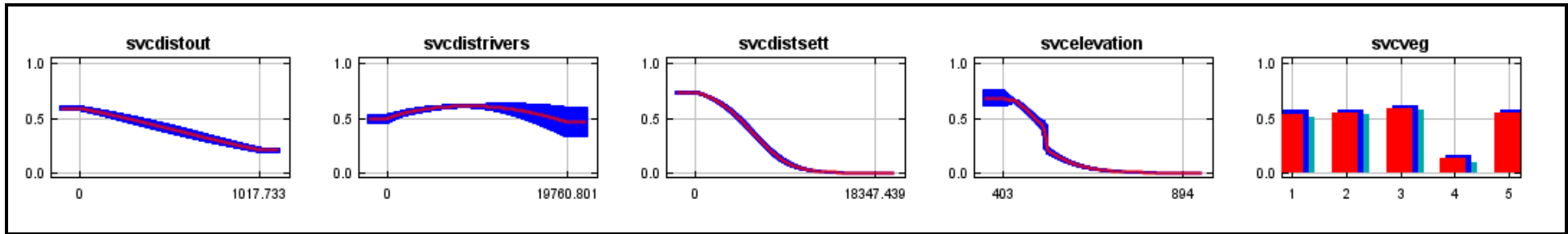


Figure E. 11 Nyarushanga response curves

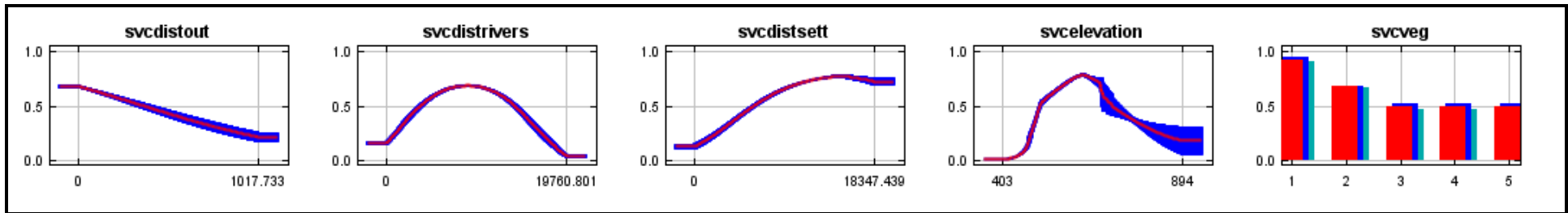


Figure E. 12 Patch response curves

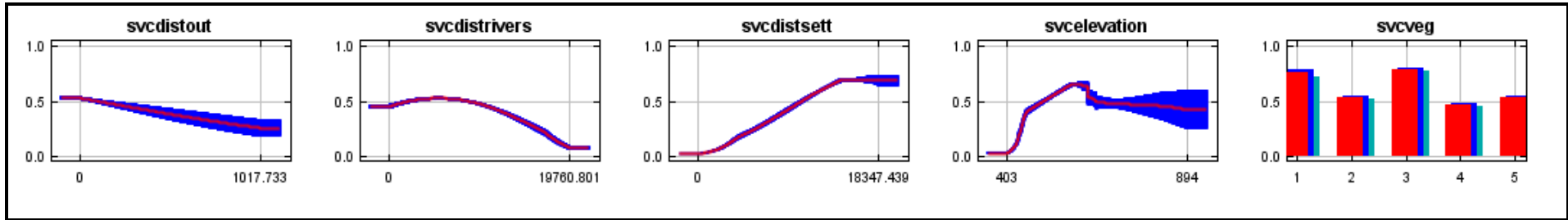


Figure E. 13 Splinters response curves

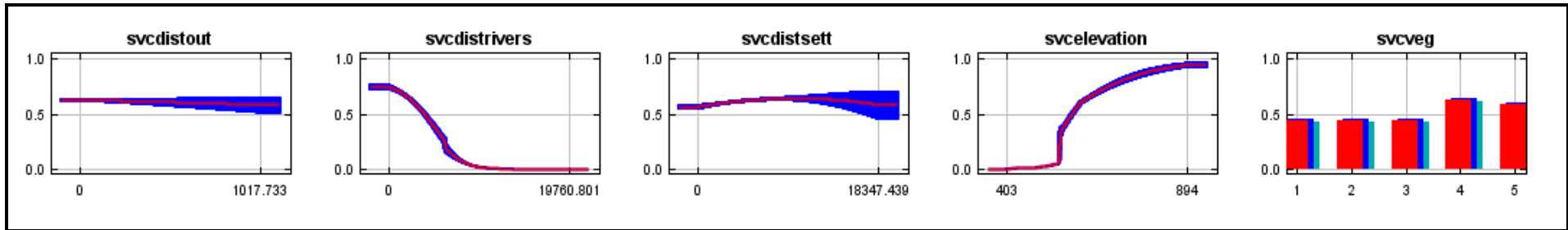


Figure E. 14 Star response curves

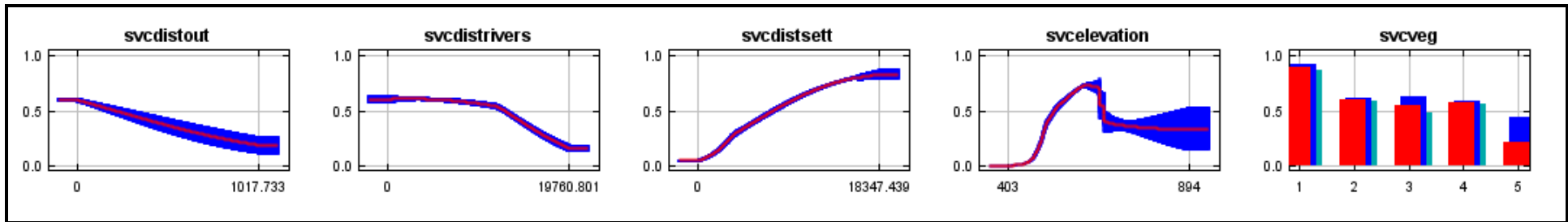


Figure E. 15 Tick response curves

APPENDIX F: MAXENT VARIABLES JACKKNIFE TESTS RESULTS PER PACK

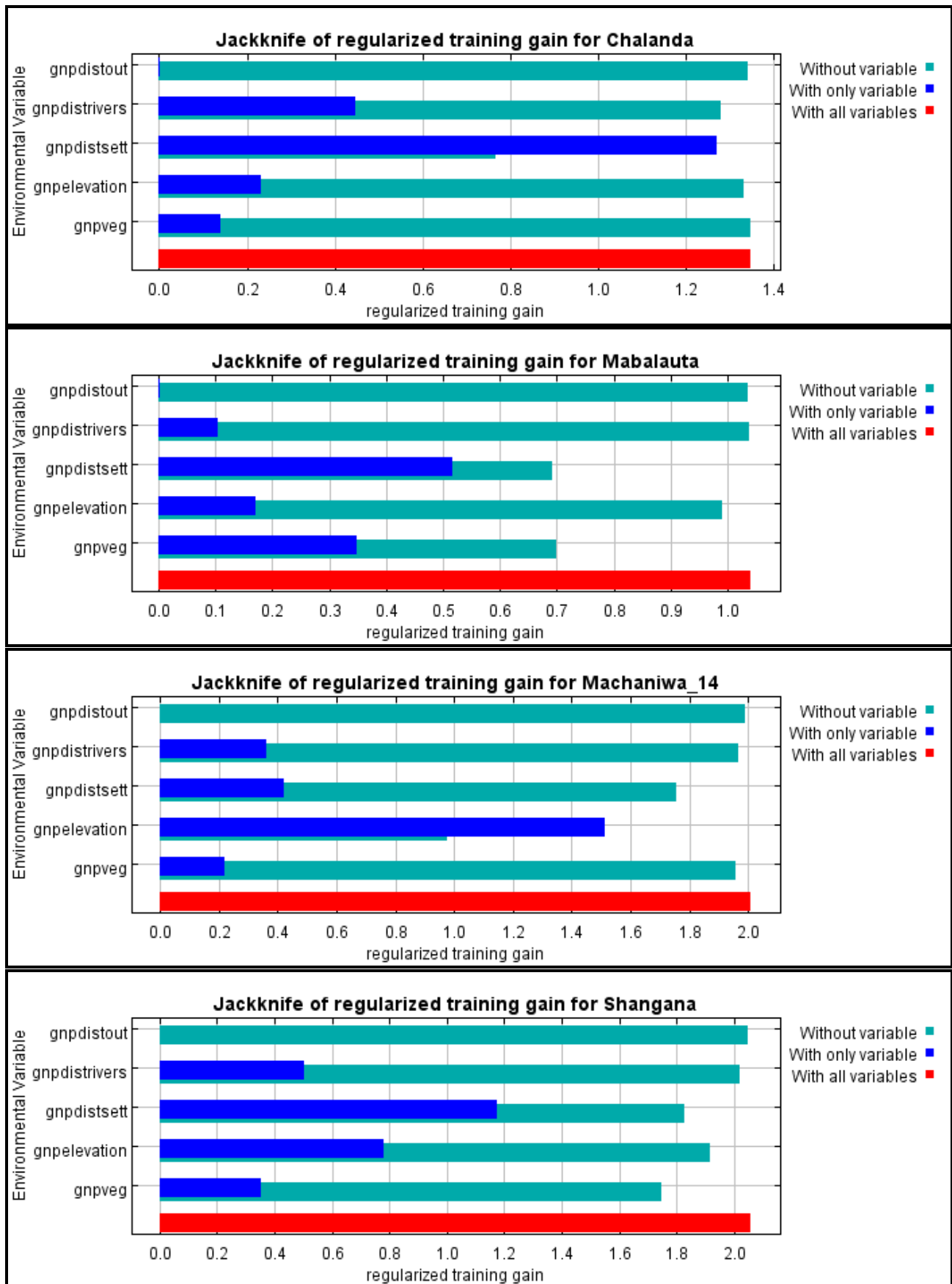
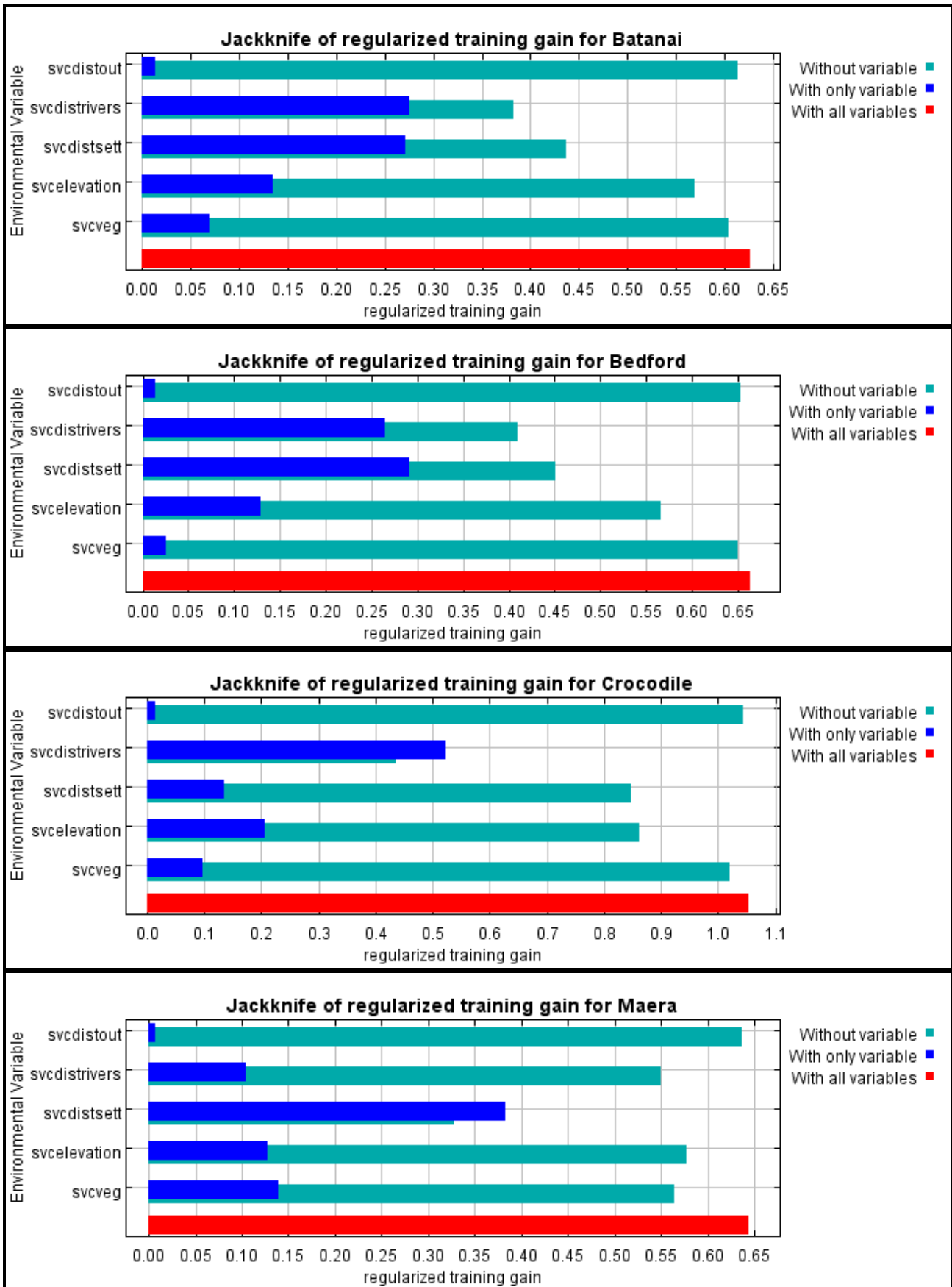
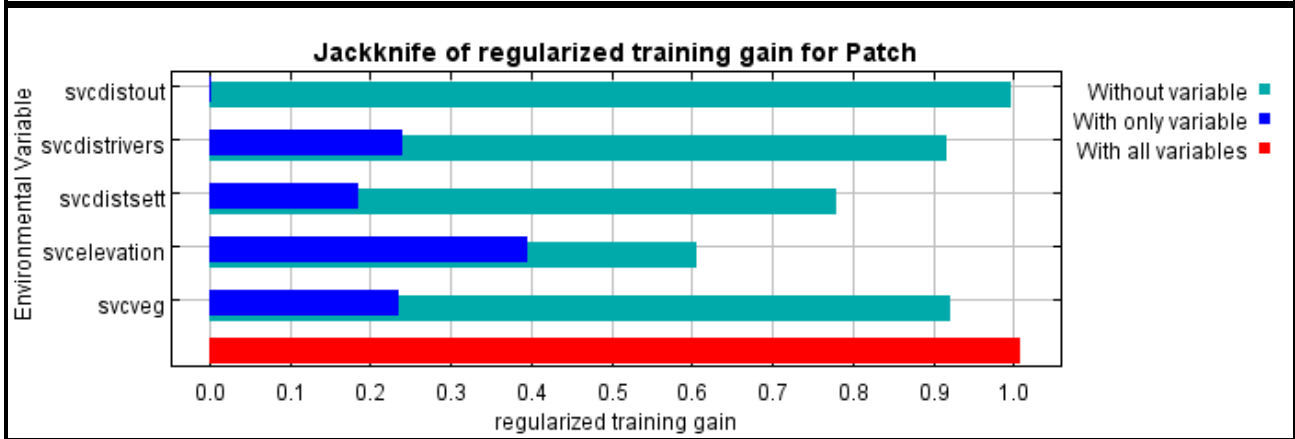
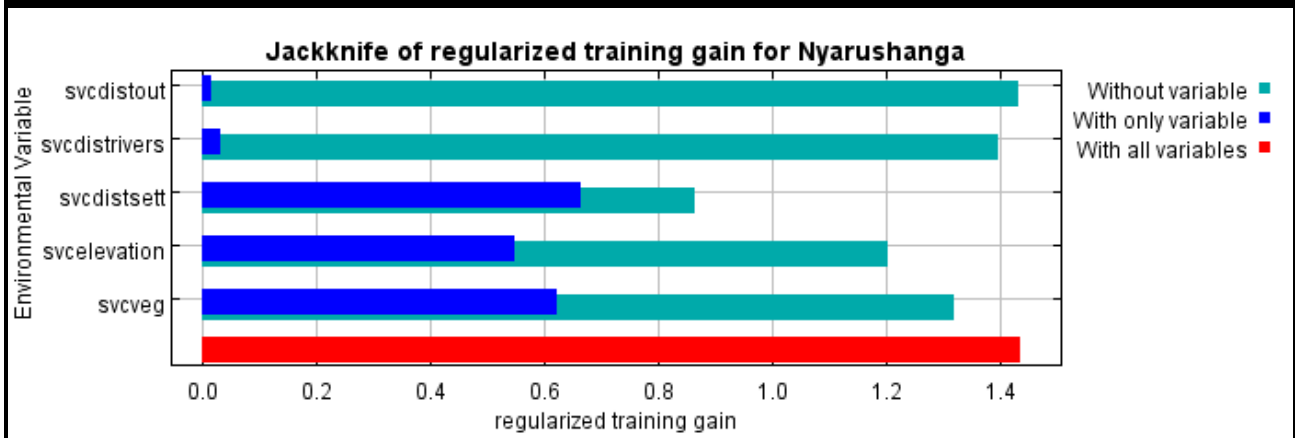
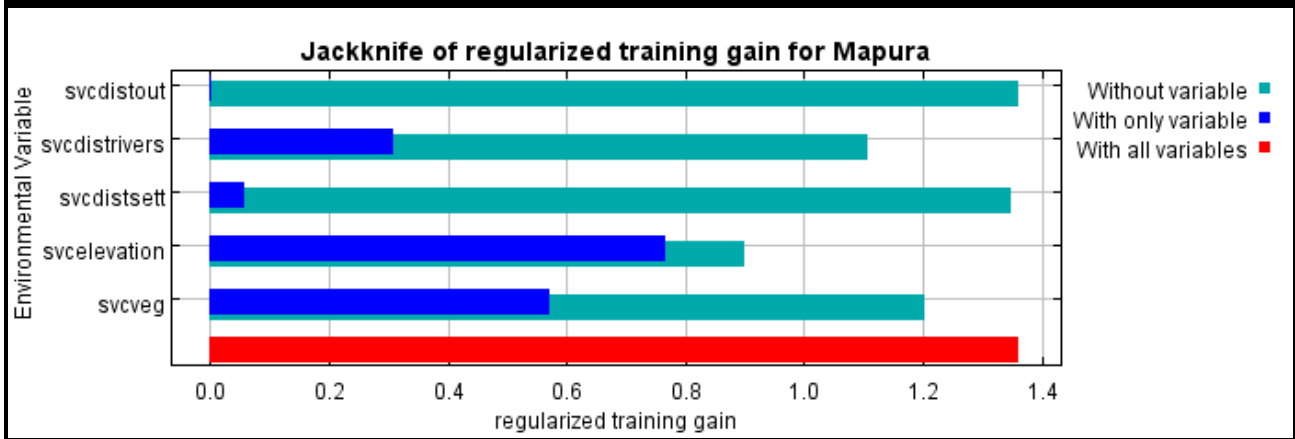
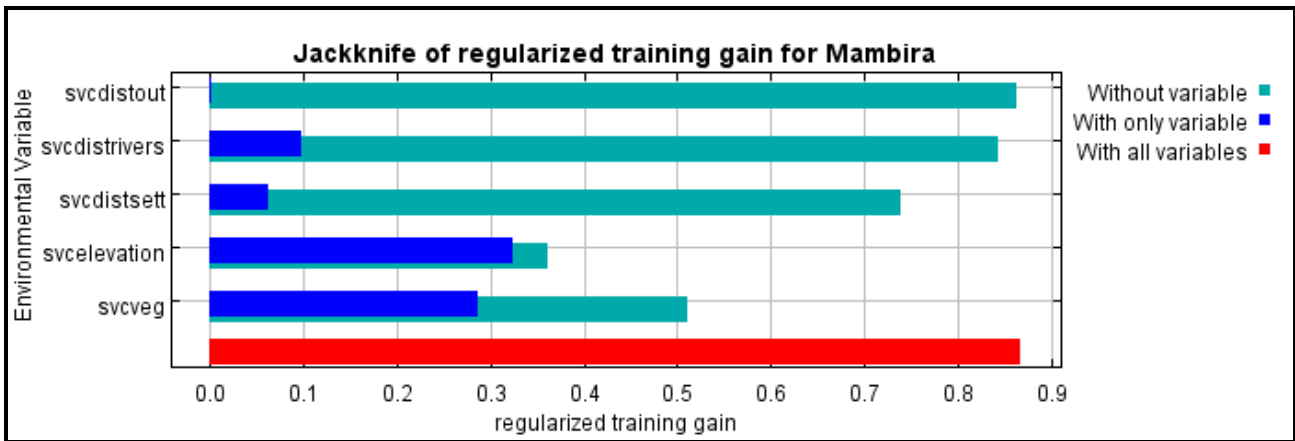


Figure F. 1 MaxEnt model Jackknife tests of each variables importance in GNP where the green is the variable's importance when the model was run without that variable, blue is only that variable and red is with all variables





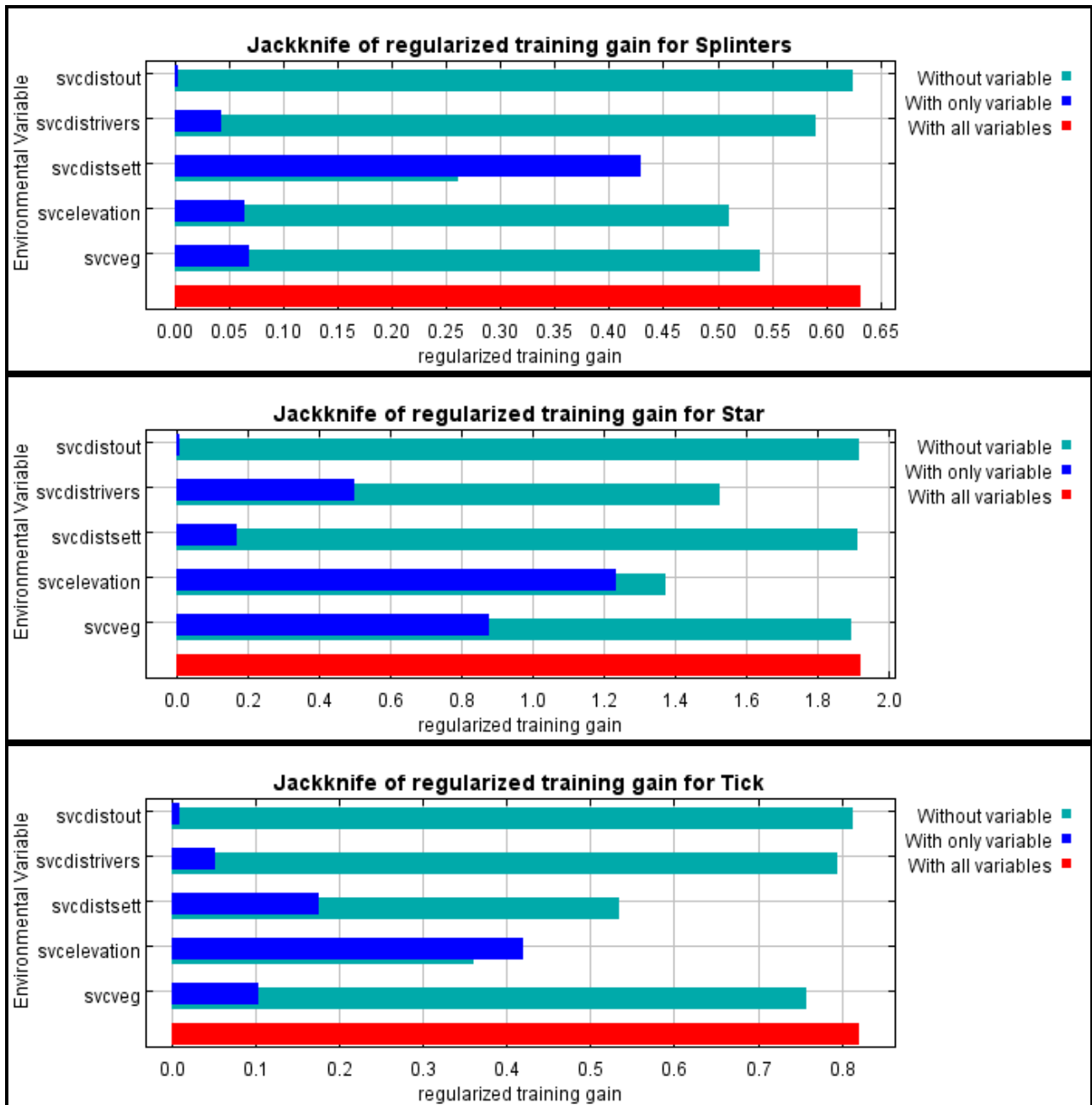


Figure F. 2 MaxEnt model Jackknife tests of each variables importance in SVC where the green is the variable's importance when the model was run without that variable, blue is only that variable and red is with all variables

APPENDIX G: MAXENT VARIABLE PERMUTATION IMPORTANCE PER PACK

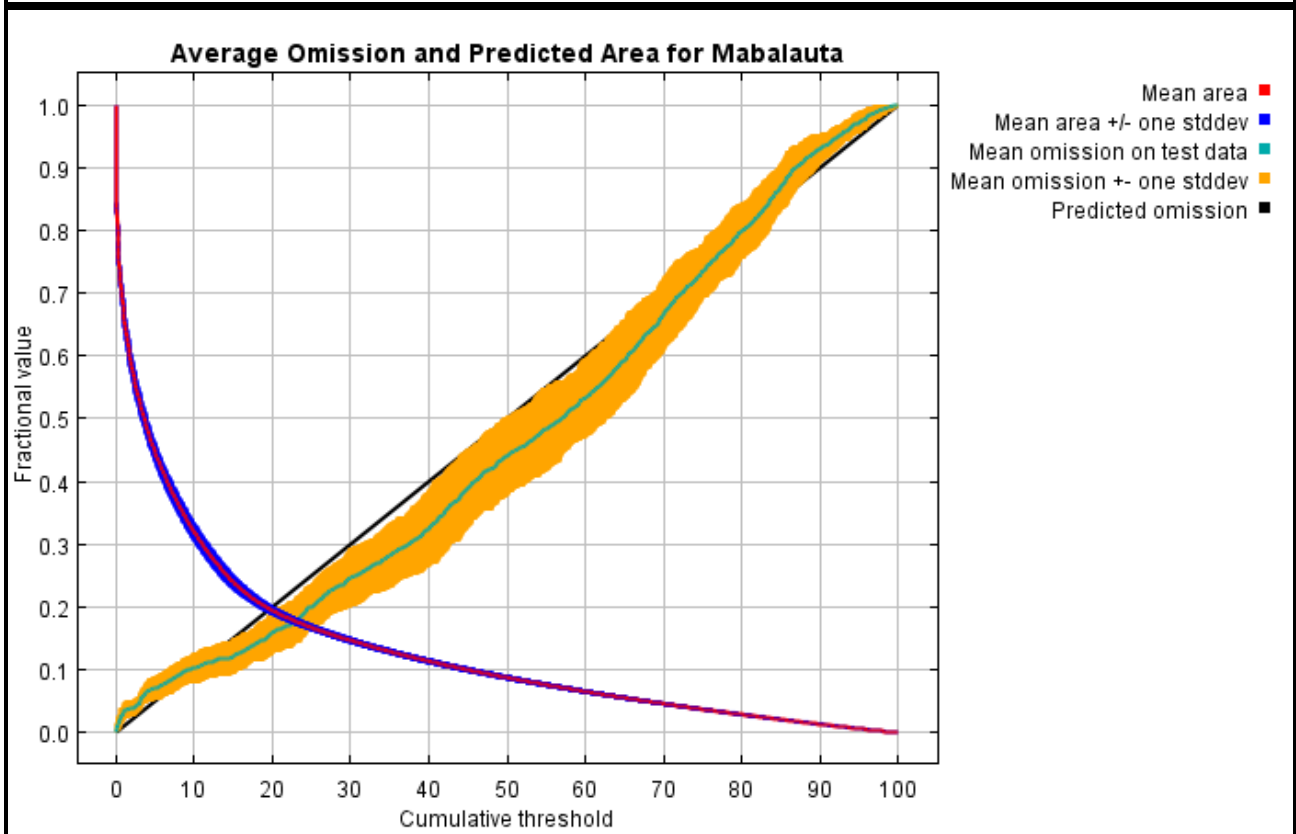
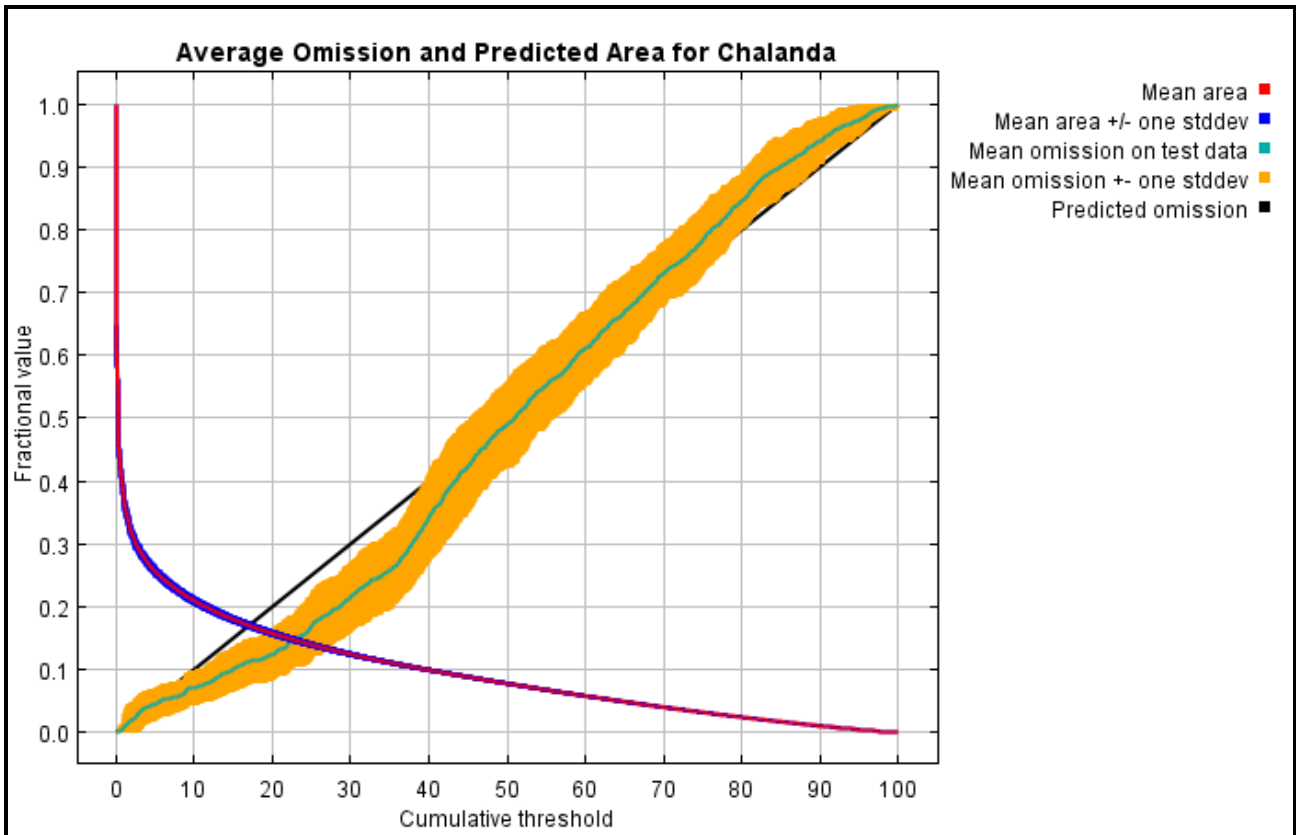
Table G. 1 MaxEnt model analysis of each variables contribution to wild dog prediction models in GNP

		Variables contribution calculated as increase in regularized gain					
Gonarezhou National Park	Wild dog pack	ROC AUC	Human settlement	Rivers	Reserve Boundary	Elevation	Vegetation
	Chalanda	0.91	89.3	6.5	0.7	3.5	0
	Mabalauta	0.87	58.6	0.4	0.8	7	33.4
	Machaniwa	0.96	19.9	8	0.1	70.2	1.8
	Shangana	0.96	65.6	7.2	0.4	14.3	12.5

Table G. 2 MaxEnt model analysis of each variables contribution to wild dog prediction models in SVC

		Variables contribution calculated as increase in regularized gain					
Save Valley Conservancy	Wild dog pack	ROC AUC	Human settlement	Rivers	Reserve Boundary	Elevation	Vegetation
	Batanai	0.81	34.6	45.9	3.9	10.4	5.1
	Bedford	0.82	29.6	42.5	1.1	22.8	3.9
	Crocodile	0.89	18.6	55	1.6	20.2	4.6
	Maera	0.83	51.5	17.6	1.2	13.2	16.5
	Mambira	0.87	10.7	0.8	0.2	48.8	39.5
	Mapura	0.91	1	27.1	0.2	59	12.7
	Nyarushanga	0.92	45.5	3.5	0	25.8	25.4
	Patch	0.90	22	16.9	0.2	49.8	11.2
	Splinters	0.82	59.9	6.6	0.2	19.4	14
	Star	0.95	0.3	39.6	0.1	59.6	0.4
	Tick	0.86	26.5	2.3	1.1	62.9	7.2

APPENDIX H: MAXENT OMISSION/COMMISSION GRAPHS RESULTS PER PACK



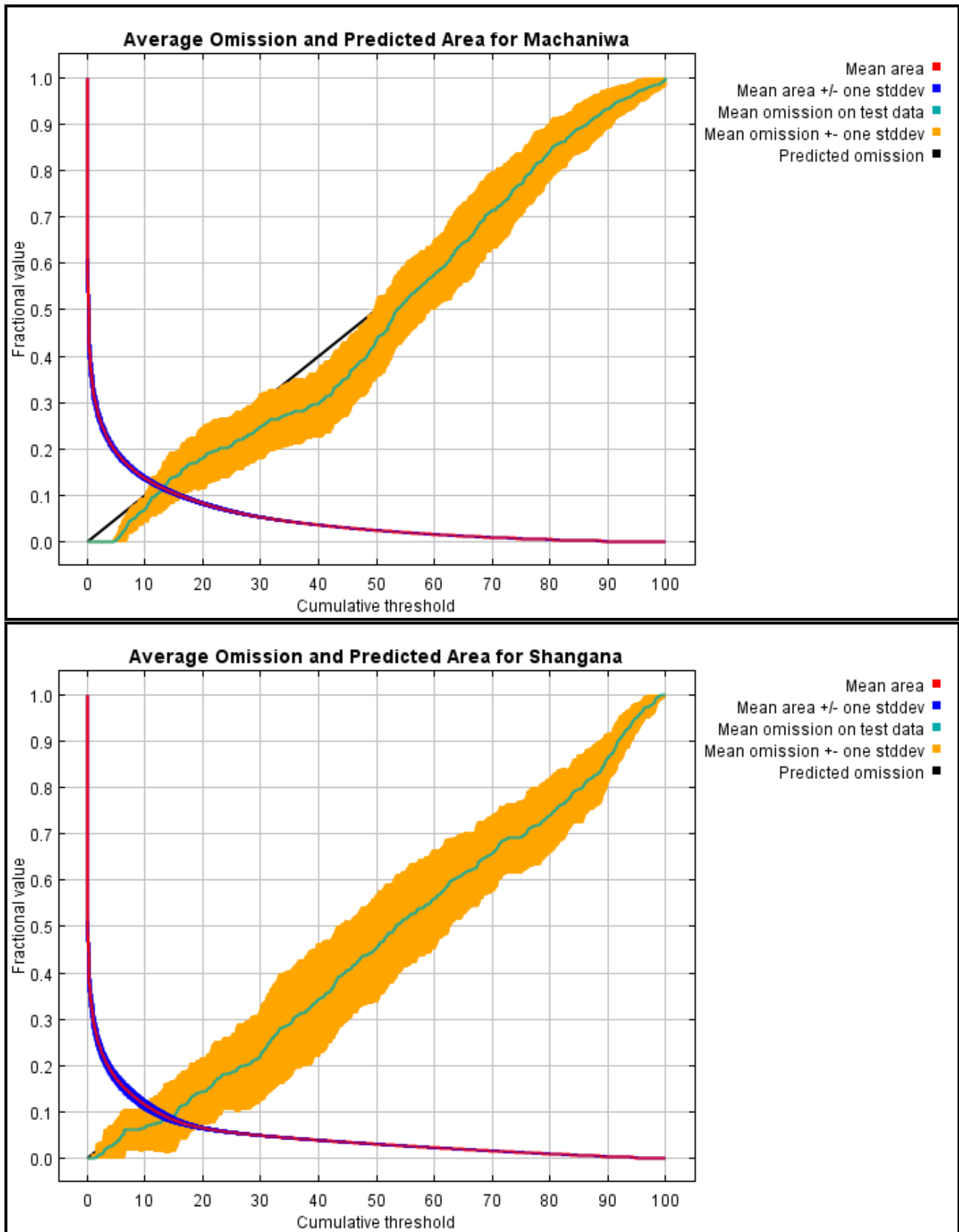
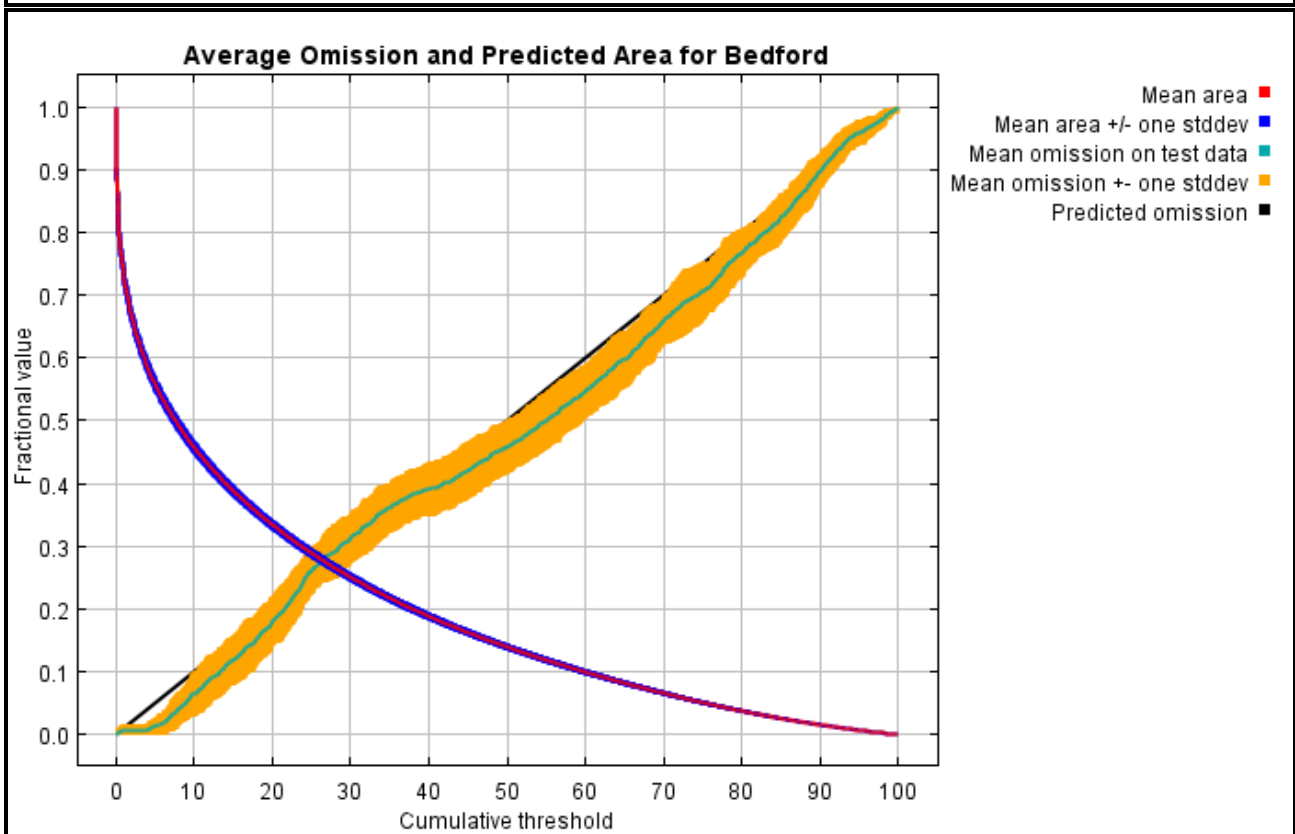
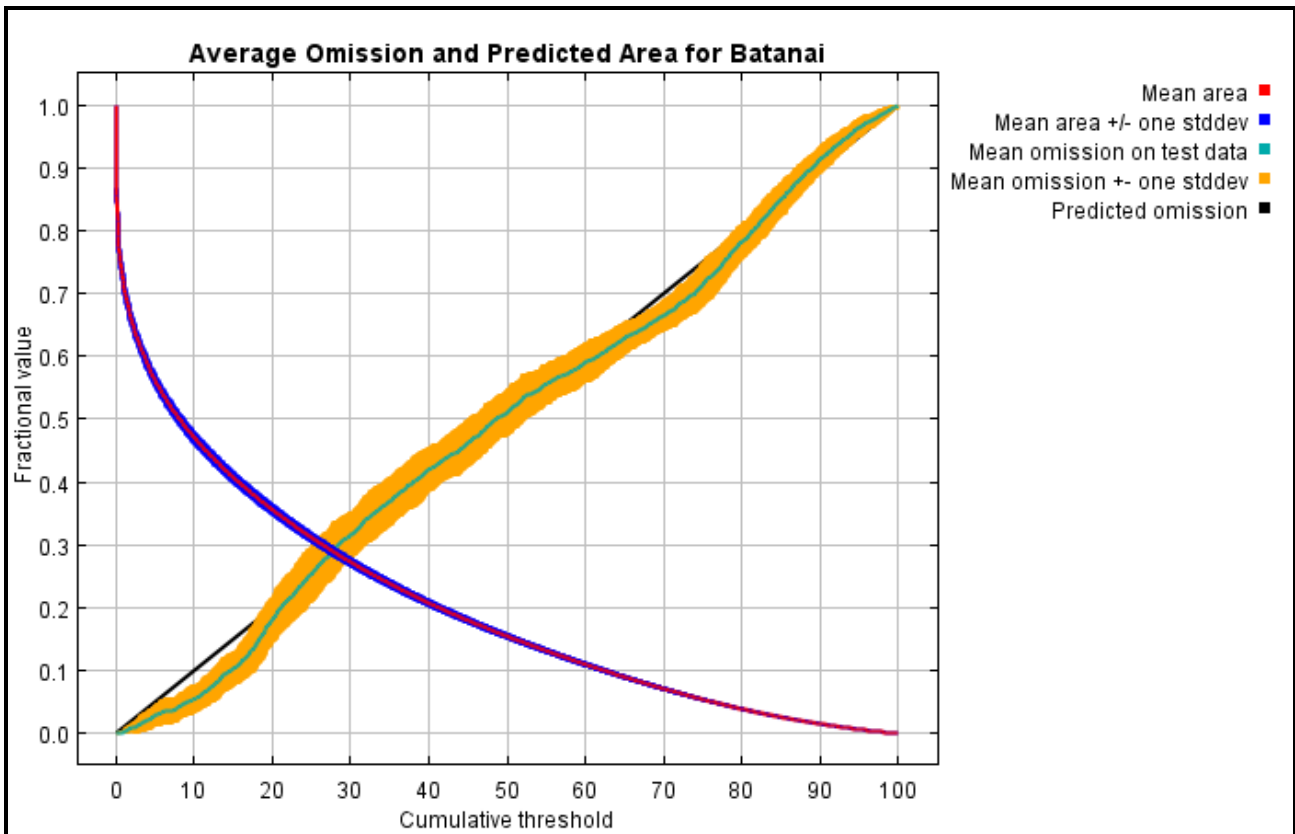
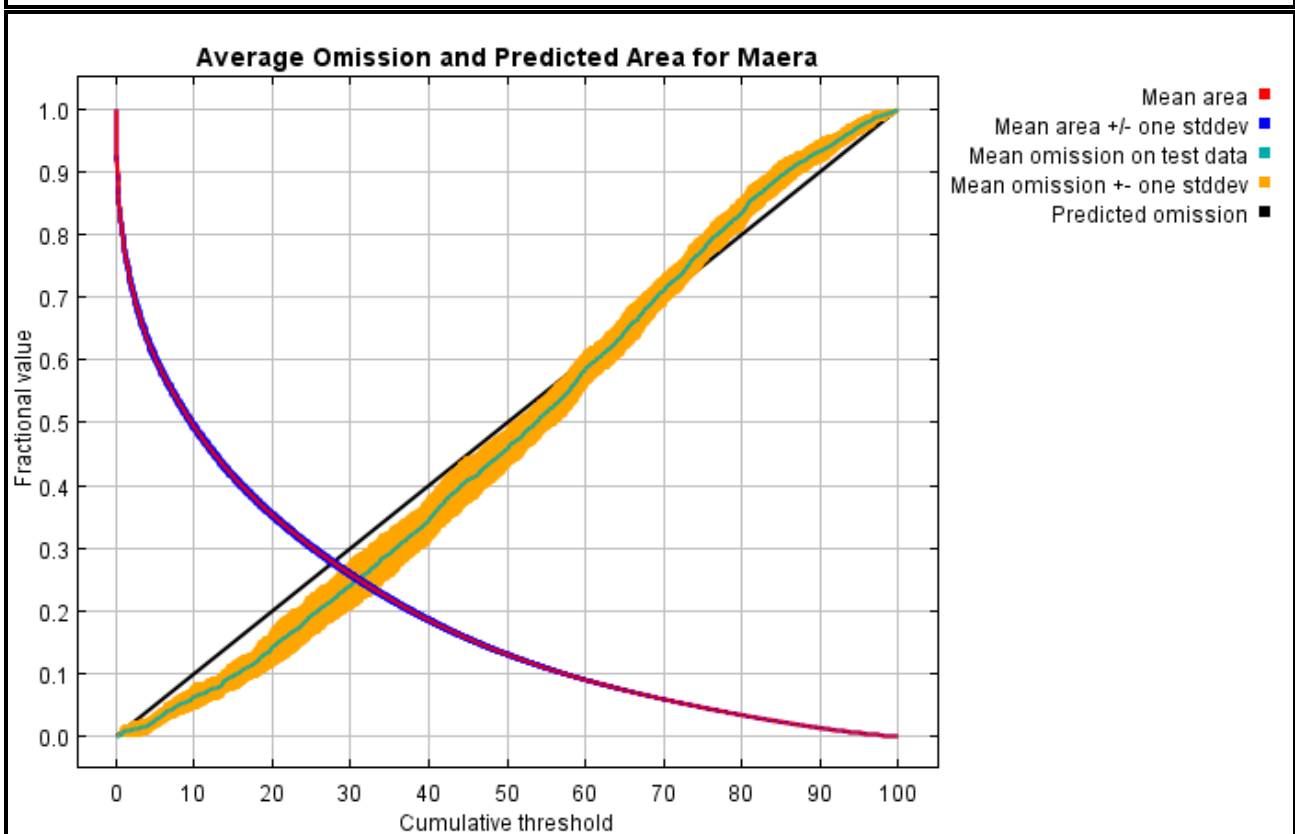
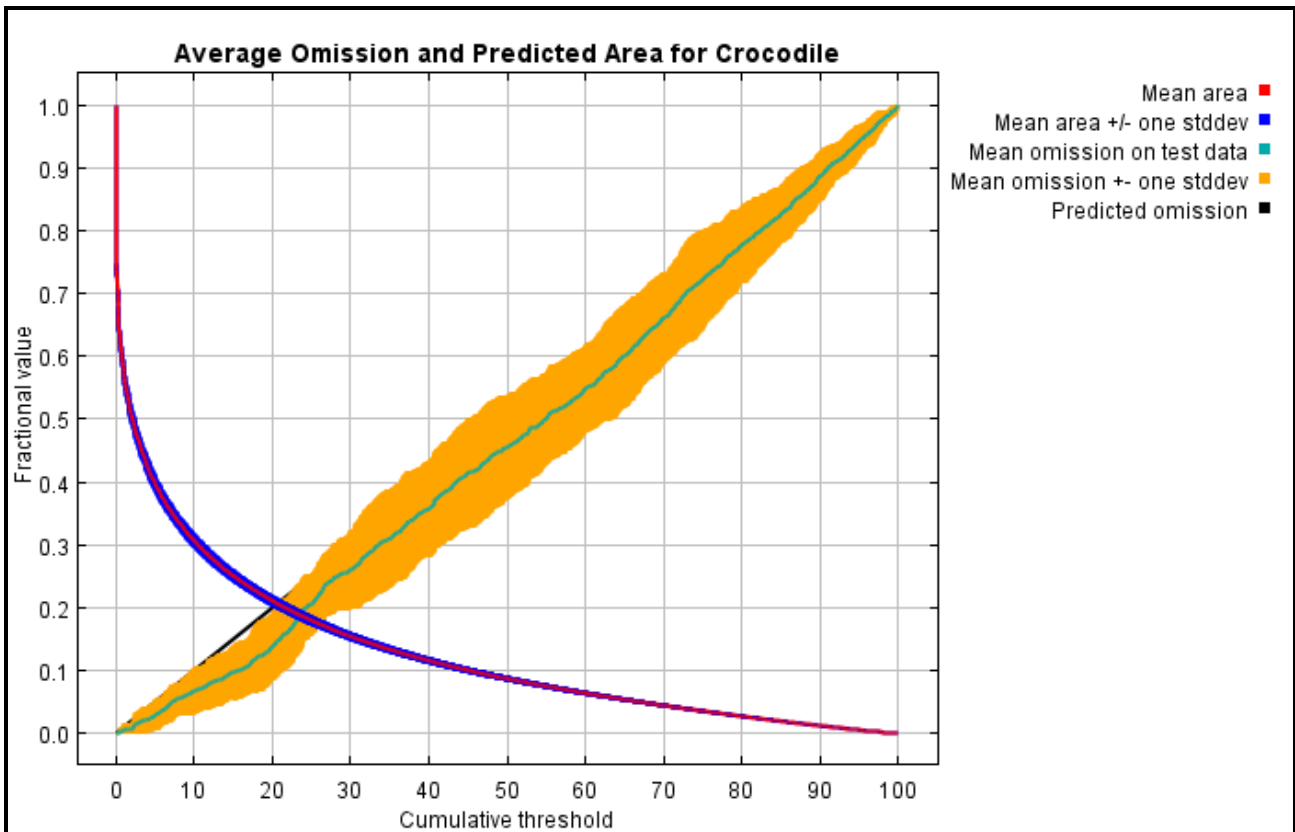
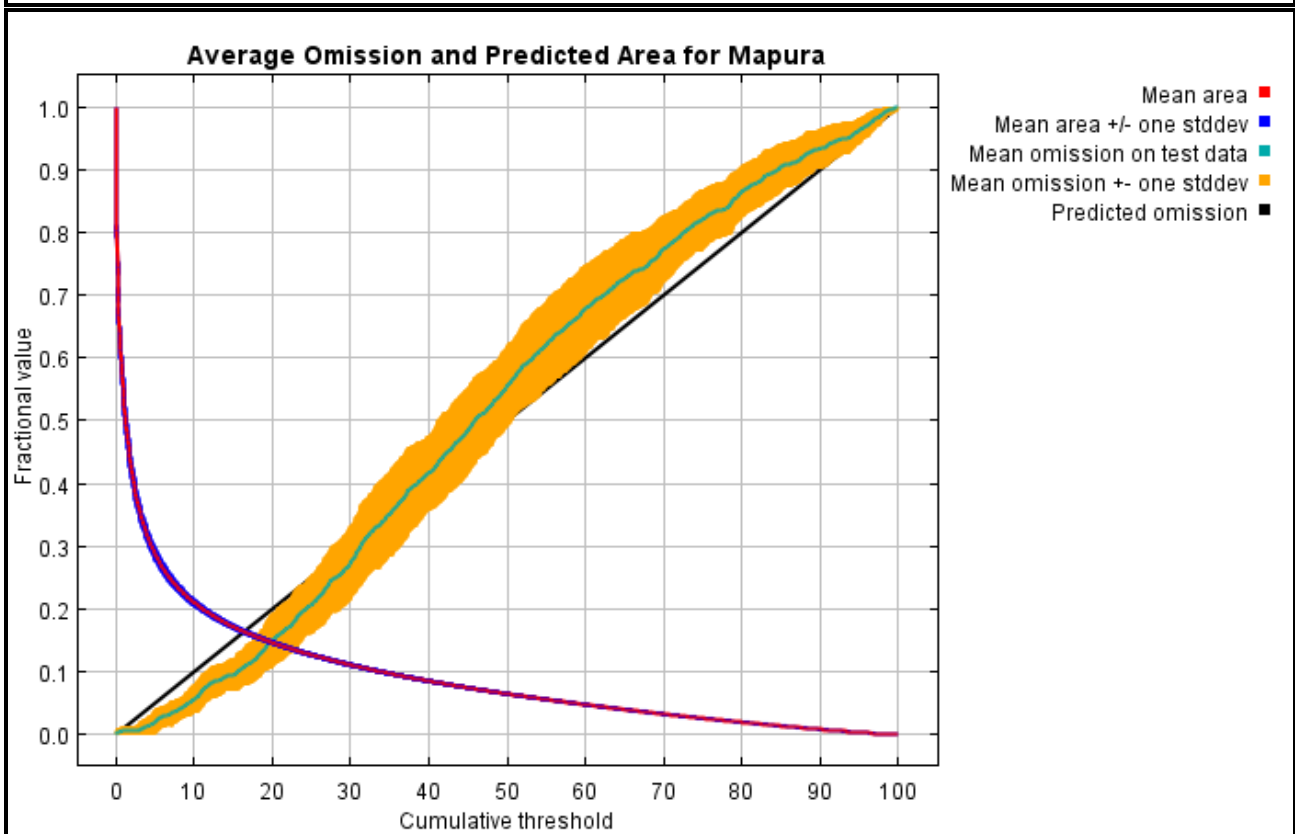
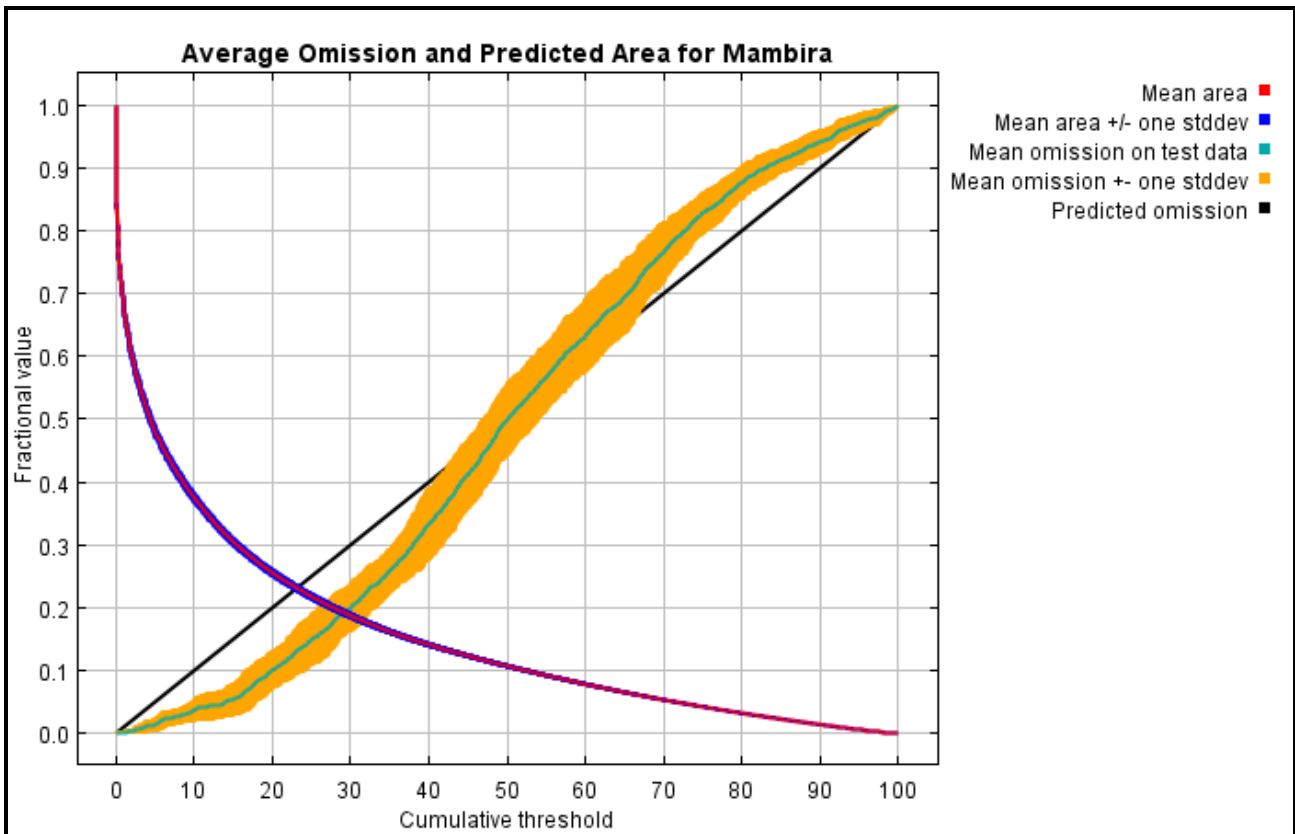
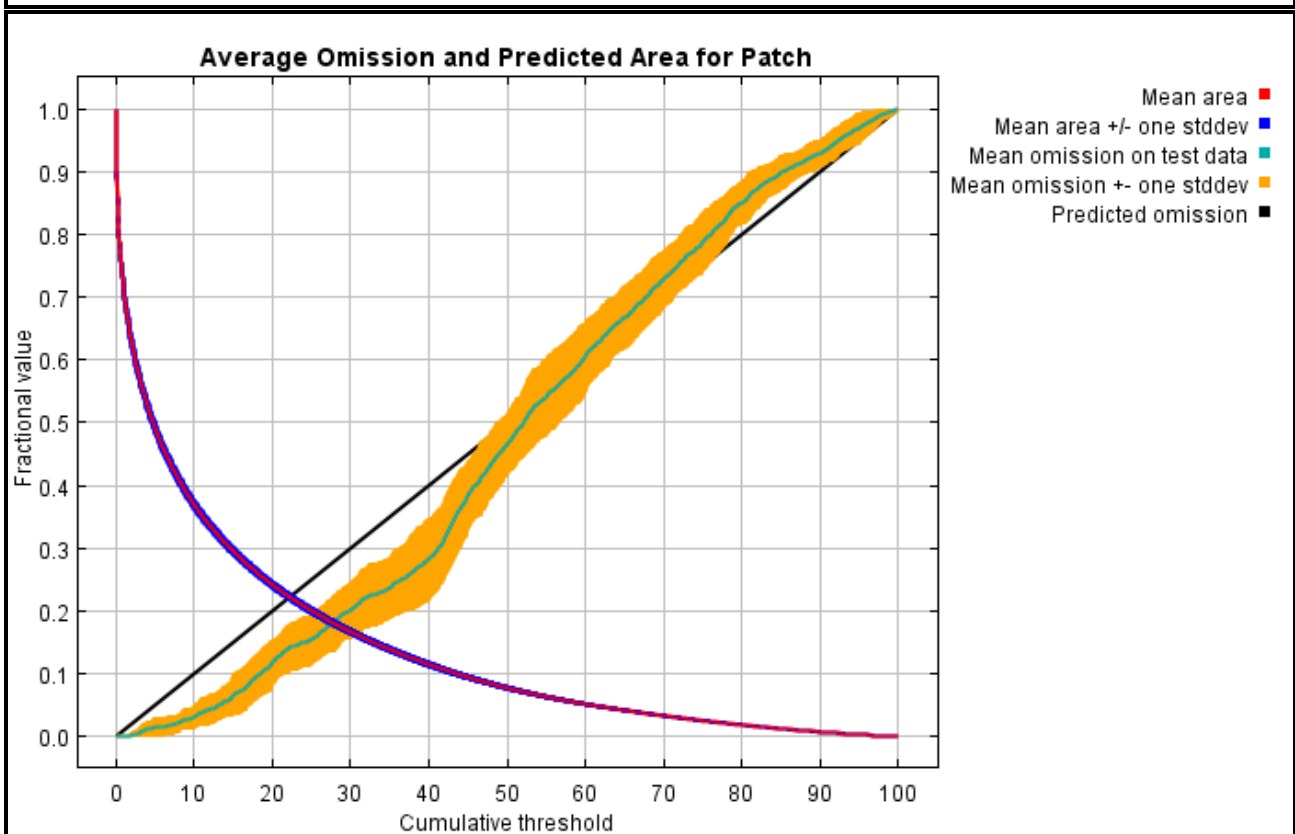
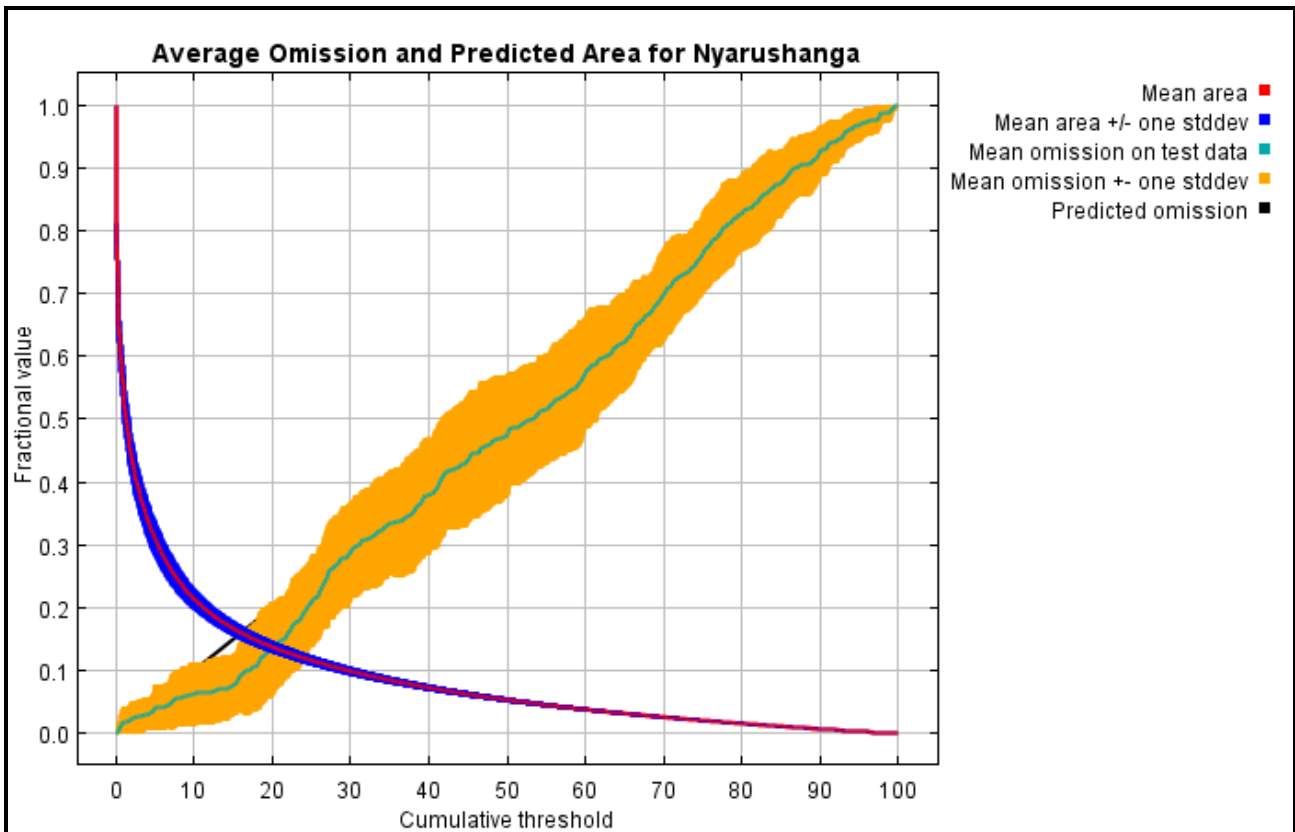


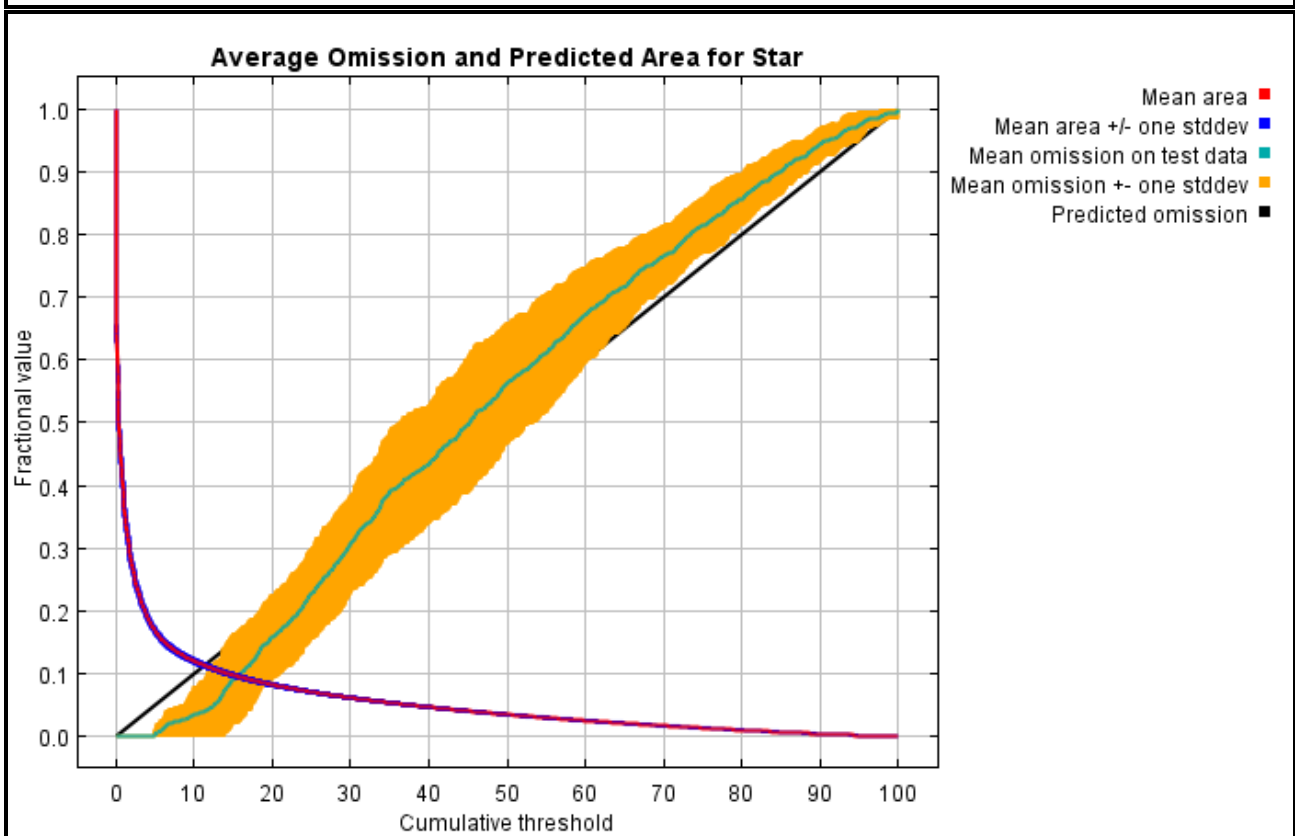
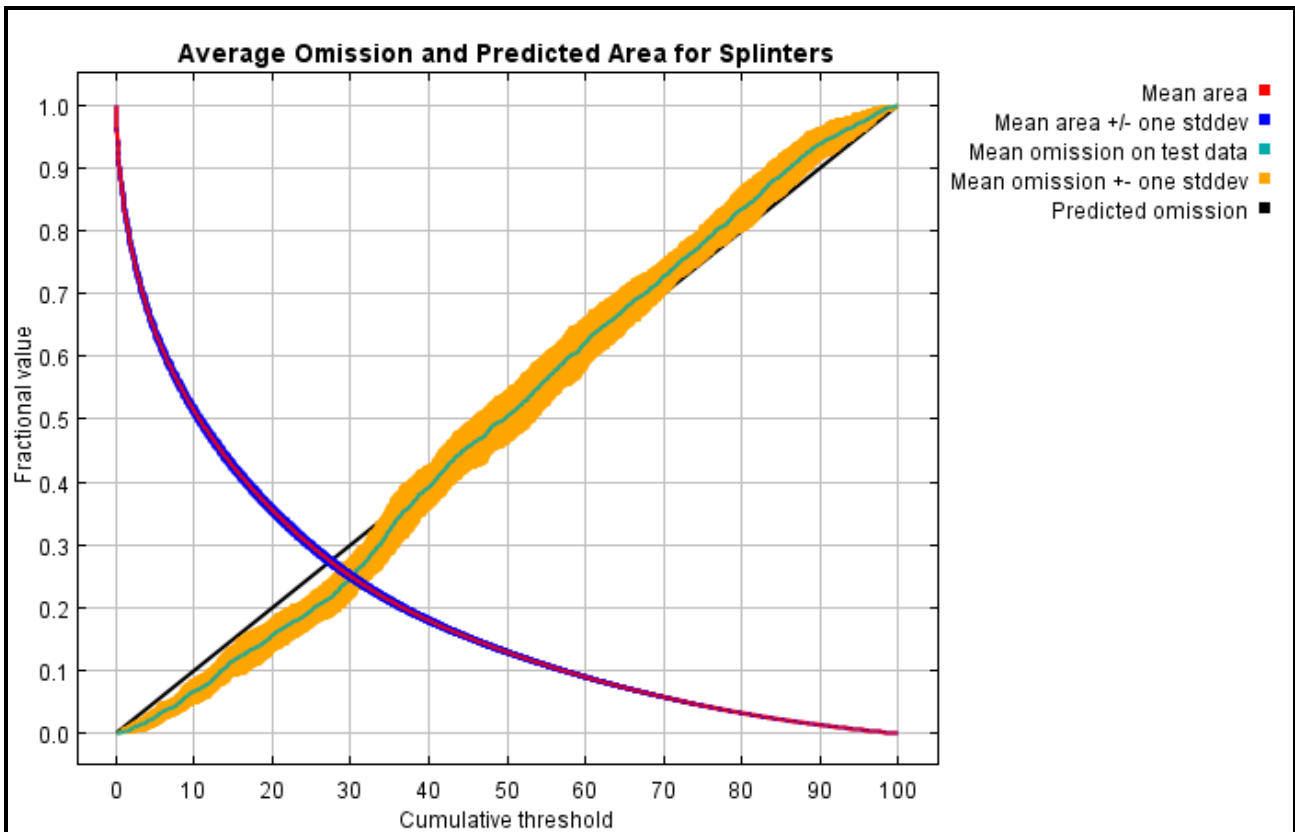
Figure H. 1 MaxEnt model omission/commission graphs in GNP











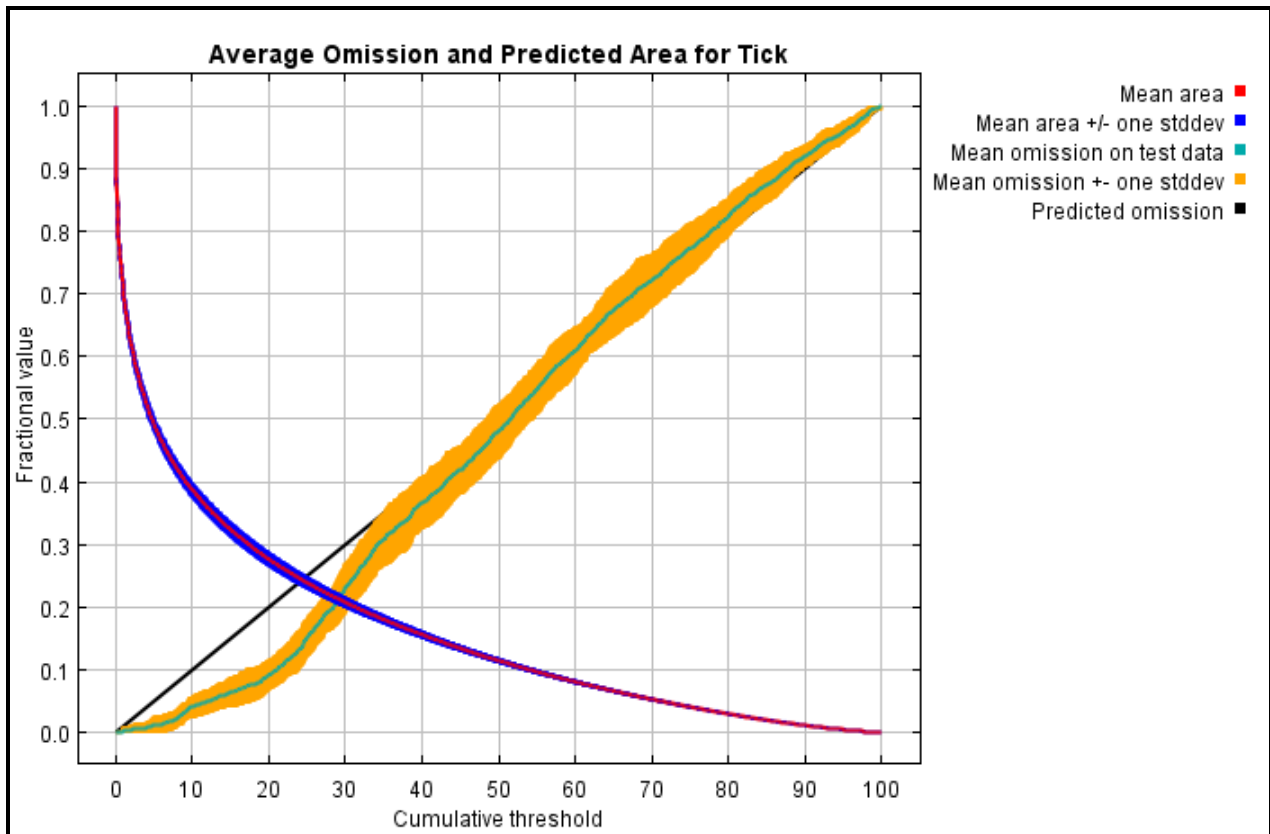


Figure H. 2 MaxEnt model omission/commission graphs in SVC

APPENDIX I: MAXENT WILD DOG DISTRIBUTION MODELS PER PACK

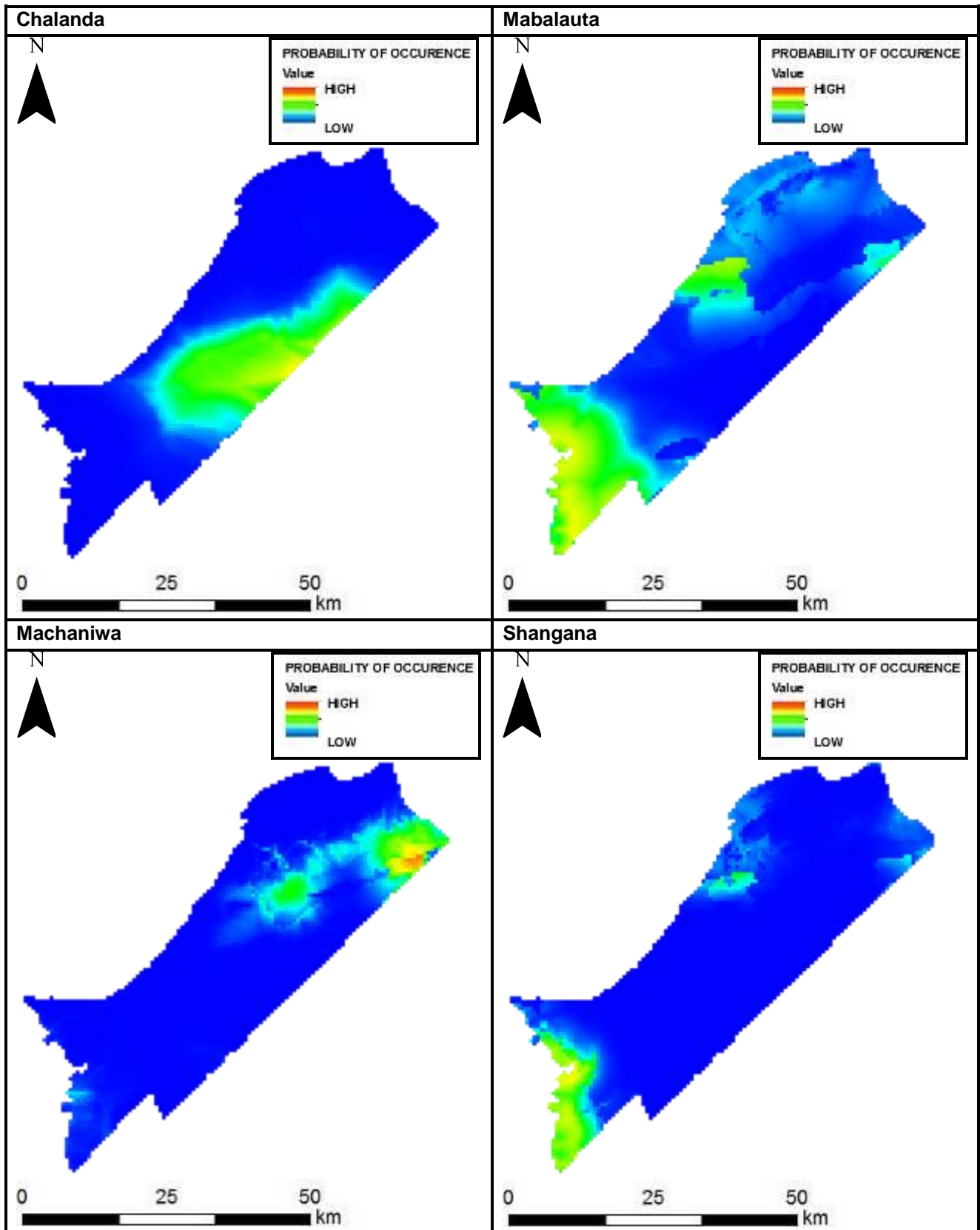
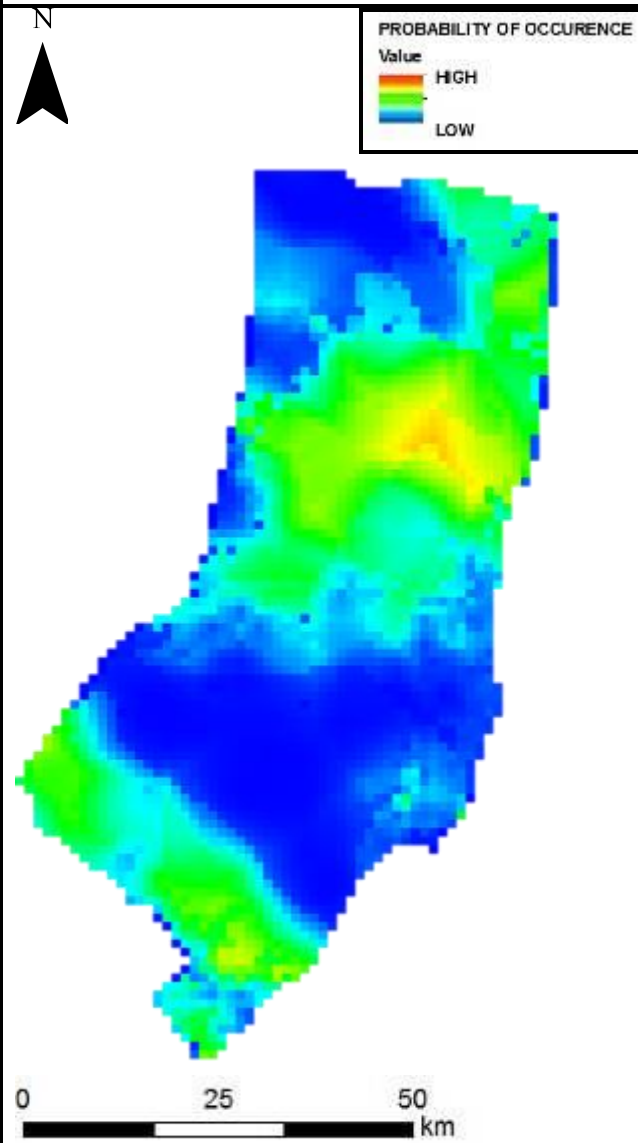
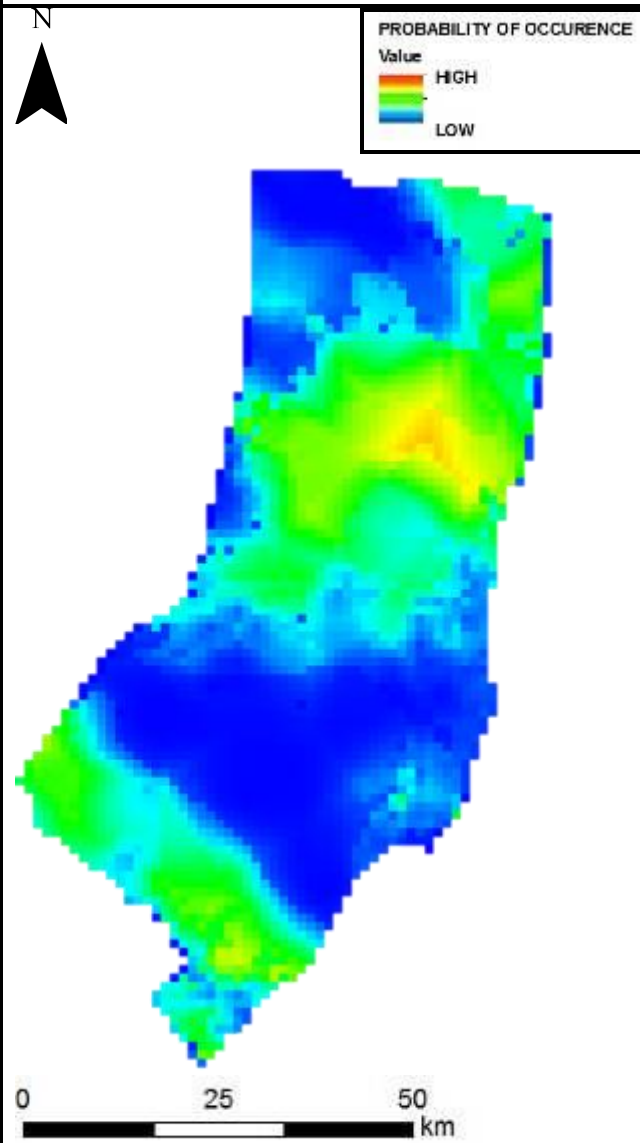


Figure I. 1 GNP wild dog MaxEnt models per pack (Chalanda, Mabalauta, Machaniwa, Shangana)

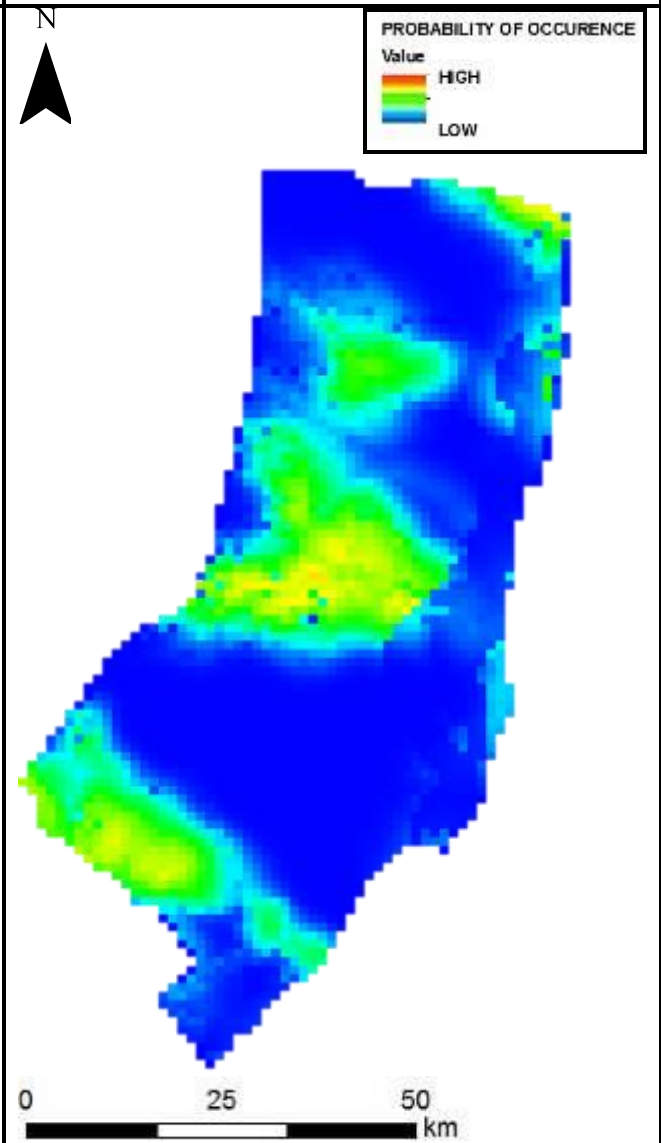
Batanai

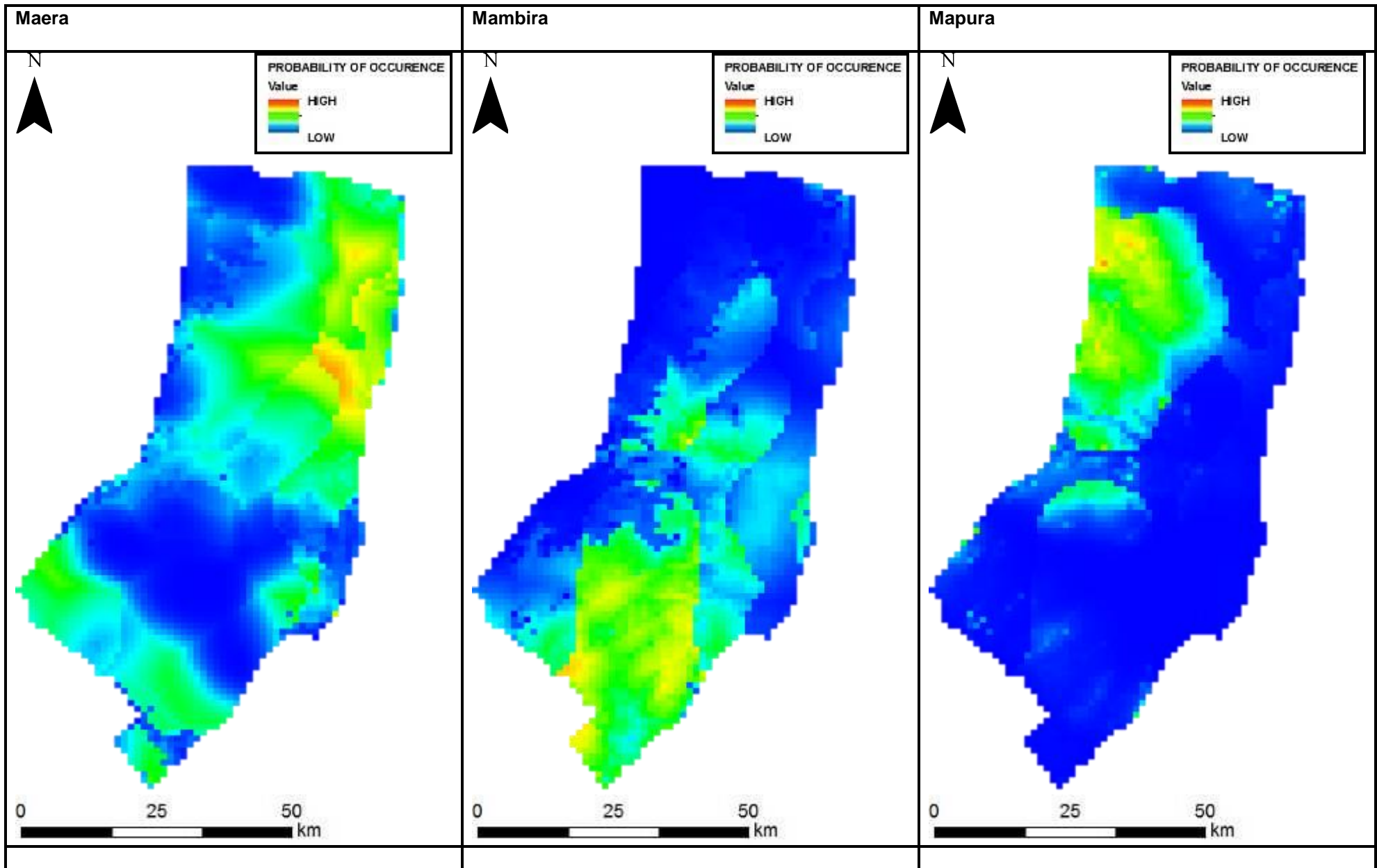


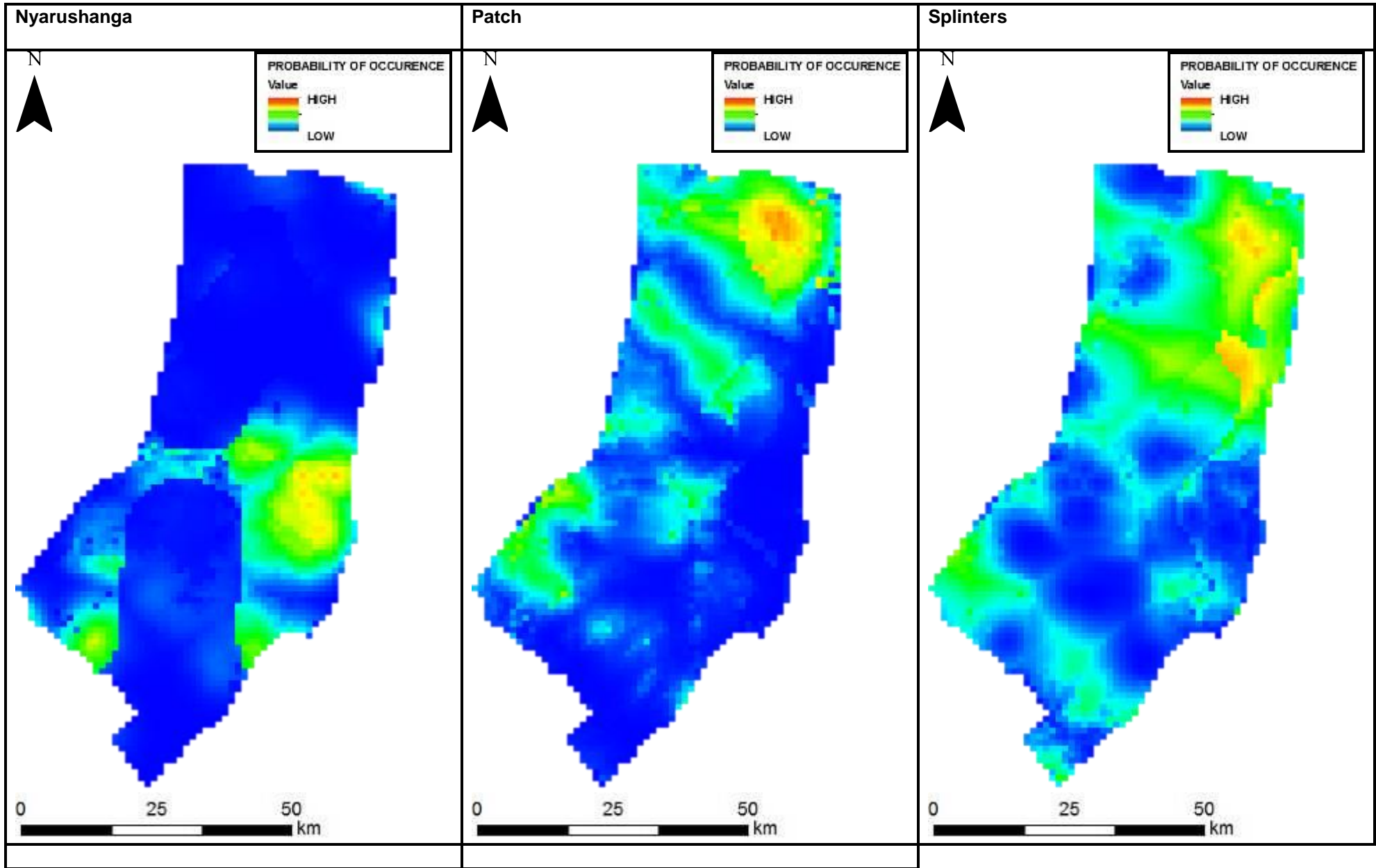
Bedford



Crocodile







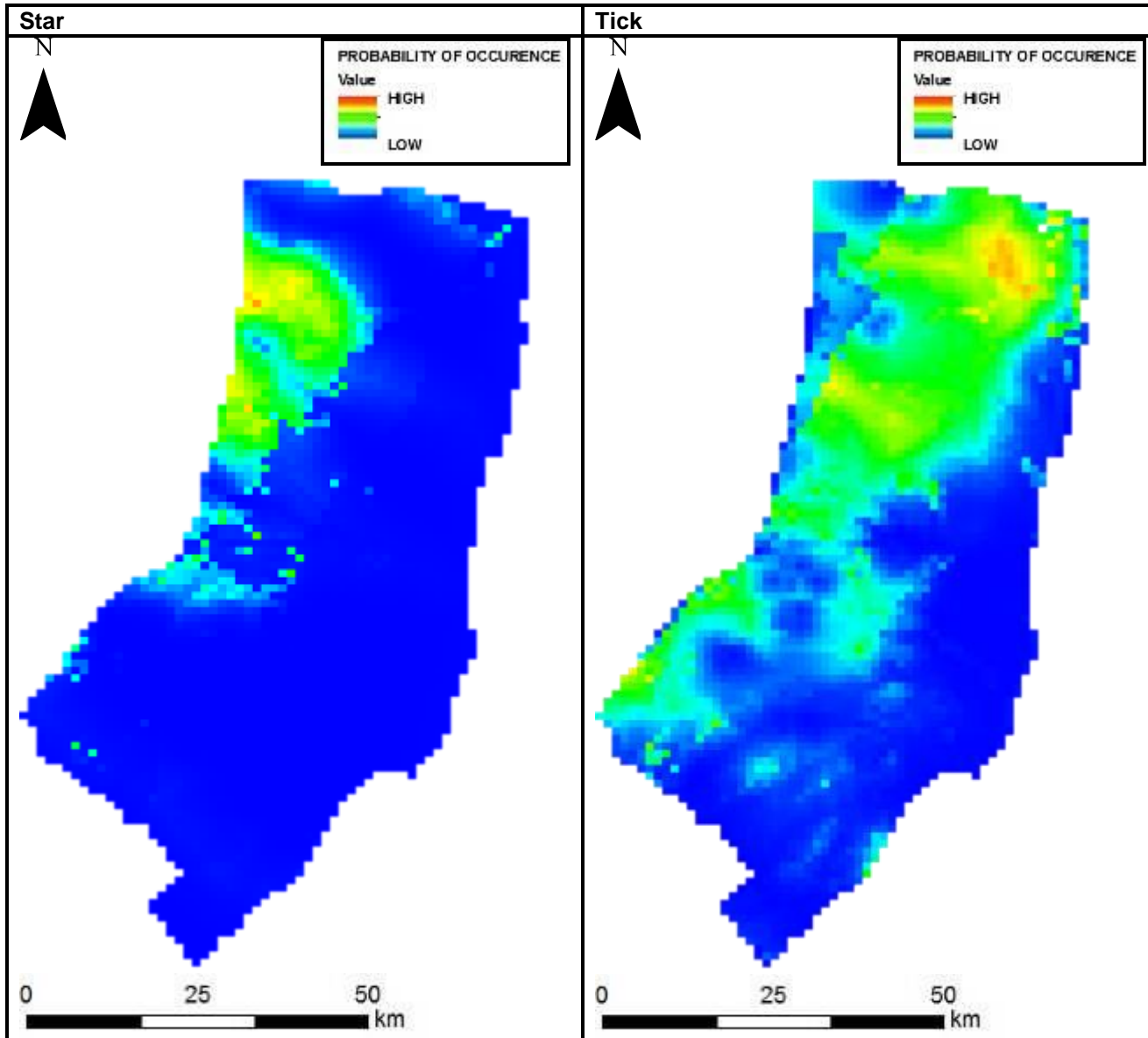


Figure I. 2 SVC wild dog MaxEnt models per pack

APPENDIX J: MAXENT WILD DOG DISTRIBUTION OUTSIDE GNP AND SVC OUTPUTS

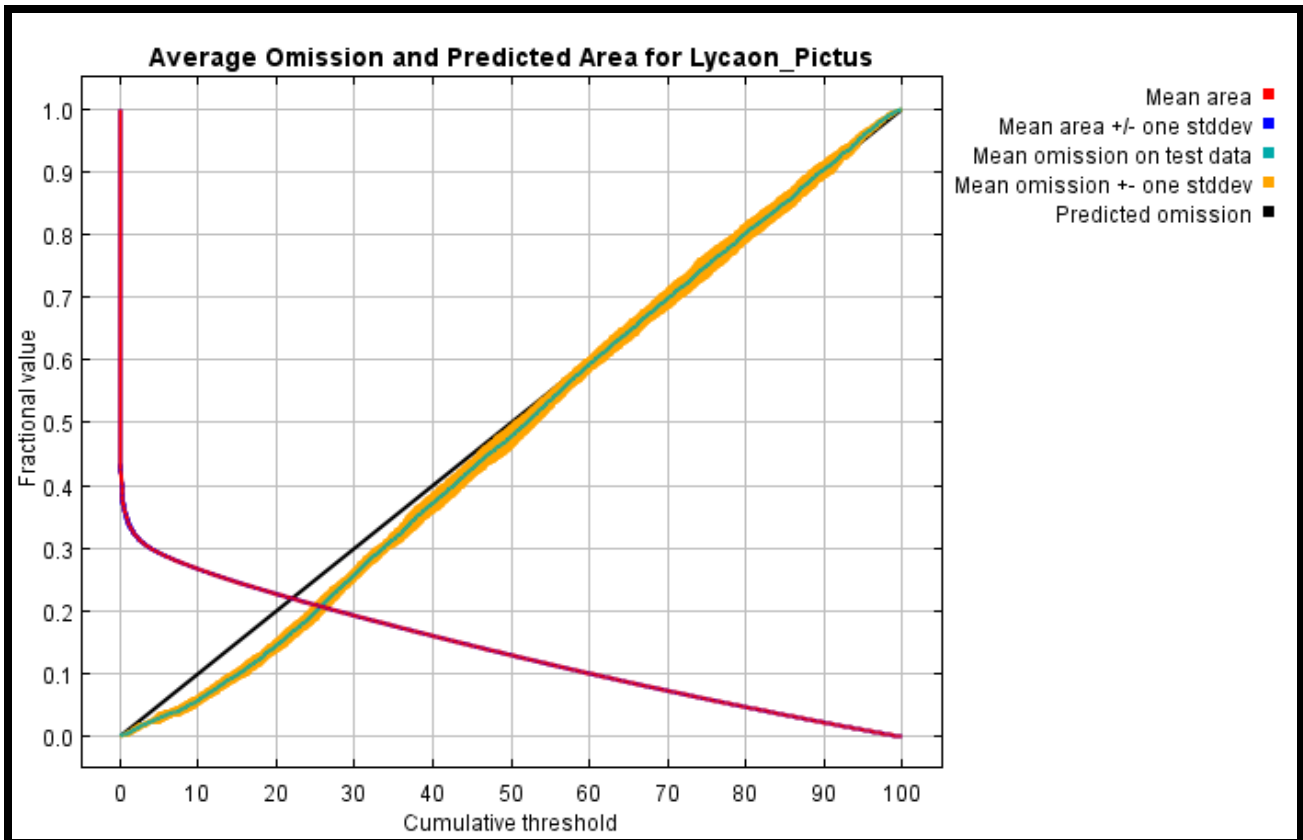


Figure J. 1 MaxEnt model omission/commission graphs in south-eastern Zimbabwe where red is the mean area, blue is mean area +/- one stddev, green is the mean omission on test data, orange is mean omission +/- one std

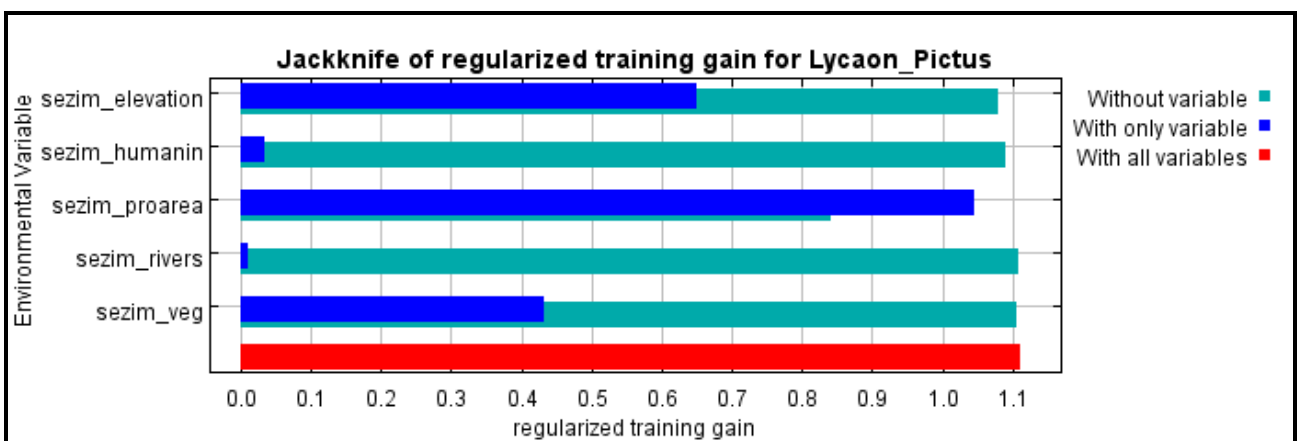


Figure J. 2 MaxEnt model Jackknife tests of each variables importance in south-eastern zimbabwe where the green is the variable's importance when the model was run without that variable, blue is the variable's import

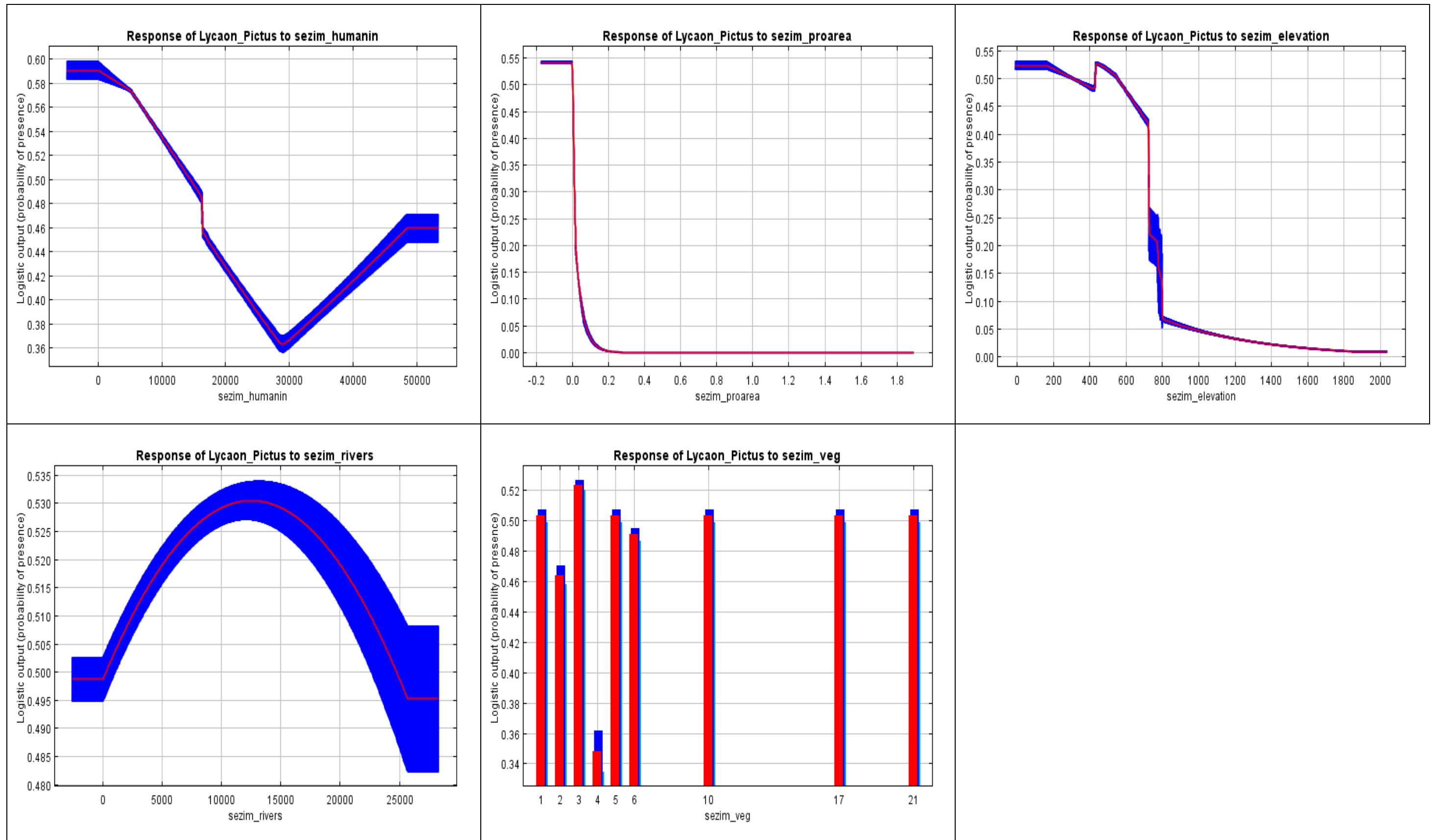


Figure J. 3 Response curves for the variables effect on predictions outside GNP and SVC plotted as logistic prediction on the y-axis against its weight in the model on the x-axis for three geographic variables (a) Distance to human influences, (b) Distance to rivers, and (c) Distance to reserve boundary, and two environmental variables (d) elevation, and (e) vegetation

APPENDIX K: ETHICAL CLEARANCE



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
Jou kennisvenoot • your knowledge partner

Approval Notice New Application

14-May-2014
Marengo, Rosebud

Proposal #: DESC/Marengo/May2014/7

Title: Geographic and environmental factors influencing connectivity of wild dog in south-eastern Zimbabwe.

Dear Ms Rosebud Marengo,

Your **New Application** received on **08-May-2014**, was reviewed
Please note the following information about your approved research proposal:

Proposal Approval Period: **13-May-2014 -12-May-2015**

Please take note of the general Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

Please remember to use your **proposal number (DESC/Marengo/May2014/7)** on any documents or correspondence with the REC concerning your research proposal.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Also note that a progress report should be submitted to the Committee before the approval period has expired if a continuation is required. The Committee will then consider the continuation of the project for a further year (if necessary).

This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health). Annually a number of projects may be selected randomly for an external audit.

National Health Research Ethics Committee (NHREC) registration number

REC-050411-032. We wish you the best as you conduct your research.

If you have any questions or need further help, please contact the REC office at 0218089183.

Included Documents: DESC application Cover letter
 Research proposal
 Data sharing agreement

Sincerely,

Clarissa Graham REC Coordinator
Research Ethics Committee: Human Research (Humanities)