UNIVERSITY OF YAOUNDE I
UNIVERSITE DE YAOUNDE I

FACULTY OF SCIENCE
FACULTE DES SCIENCES

DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY
DEPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE ANIMALES
LABORATORY OF ZOOLOGY
LABORATOIRE DE ZOOLOGIE

Influence of habitat on pangolins' (Pholidota: Manidae) feeding behavior, potential and effective diet composition in two forest-savanna mosaic zones of Cameroon

Thesis submitted in partial fulfillment of the requirements for a
Doctorate/Ph.D. degree in Biology of Animal Organisms
Option Zoology
by
DIFOUO FOPA Ghislain
Registration number: 10Q0119
Master of Science

Publicly defended on June 29, 2023 before the committee constituted as follows:

President: **BILONG BILONG Charles Félix**, *Professor*, University of Yaoundé 1;

Supervisors: **KEKEUNOU Sévilor**, *Professor*, University of Yaoundé 1;
OLSON David, *Director of Research,* NEOM Nature Reserve;

Members: **DJIETO-LORDON Champlain**, *Professor*, University of Yaoundé 1;
MONY Ruth, Epse NTONE, *Associate Professor*, University of Yaoundé 1;
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Year 2023

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FACULTE DES SCIENCES
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ATTESTATION DE CORRECTION

Conformément à l'autorisation de soutenance de la thèse de Doctorat/Ph.D N°090-2023/ UYI/CRFD_SVSE /URFD-SV/Ad/ du 05 avril 2023 de Monsieur le Recteur de l'Université de Yaoundé I, la thèse intitulée **« Influence of habitat on pangolins' (Pholidota: Manidae) feeding behavior, potential and effective diet composition in two savanna mosaic zones »** a été présentée et soutenue publiquement le **jeudi 29 juin 2023** par l'étudiant **DIFOUO FOPA Ghislain**, Matricule **10Q0119**. Le document final a été corrigé suivant les recommandations du jury.

En foi de quoi la présente attestation est délivrée pour servir et valoir ce que de droit.

Fait à Yaoundé, le 26 OCT 2023

Le Président du Jury

Charles Félix Bilong Bilong
Professeur

Les Examinateurs

R. MONY

C Djietolord

Le Chef de Département

Le Chef de Département
The Head of Department

Charles Félix Bilong Bilong
Professeur

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LIST OF PERMANENT TEACHING STAFF		**LISTE DES ENSEIGNANTS PERMANENTS**

LIST OF PERMANENT TEACHERS IN THE FACULTY OF SCIENCE

THE ACADEMIC YEAR 2022/2023

(By Department and by Rank)

UPDATE on May 31, 2023

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VICE-DEAN /DPSAA: ATCHADE Alex de Théodore, *Associate Professor*
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Head of Academic Affairs, Education and Research Division DAASR: AJEAGAH Gideon AGHAINDUM, *Professor*

1- DEPARTMENT OF BIOCHEMISTRY (BC) (43)

No.	SURNAME AND GIVEN NAMES	RANK	OBSERVATIONS
1.	BIGOGA DAIGA Jude	Professor	In service
2.	FEKAM BOYOM Fabrice	Professor	In service
3.	KANSCI Germain	Professor	In service
4.	MBACHAM FON Wilfred	Professor	In service
5.	MOUNDIPA FEWOU Paul	Professor	*Head of Department*
6.	NGUEFACK Julienne	Professor	In service
7.	NJAYOU Frederic Nico	Professor	In service
8.	OBEN Julius ENYONG	Professor	In service
9.	ACHU Thank you BIH	Associate Professor	In service
10.	ATOGHO Barbara MMA	Associate Professor	In service
11.	AZANTSA KINGUE GABIN BORIS	Associate Professor	In service
12.	BELINGA born NDOYE FOE FMC	Associate Professor	*Head of DAF / FS*
13.	DJUIDJE NGOUNOUE Marceline	Associate Professor	In service
14.	DJUIKWO NKONGA Ruth Viviane	Associate Professor	In service
15.	EFFA ONOMO Pierre	Associate Professor	*Vice Deam/FS/Univ Ebwa*
16.	EWANE Cécile Annie	Associate Professor	In service
17.	KOTUE TAPTUE Charles	Associate Professor	In service
18.	LUNGA Paul KEILAH	Associate Professor	In service
19.	MBONG ANGIE Mr Mary Anne	Associate Professor	In service
20.	MOFOR born TEUGWA Clotilde	Associate Professor	*Dean FS / UDs*
21.	NANA Louise marries WAKAM	Associate Professor	In service
22.	NGONDI Judith Laure	Associate Professor	In service
23.	TCHANA KOUATCHOUA Angele	Associate Professor	In service
24.	AKINDEH MBUH NJI	Lecturer	In service
25.	BABY Fadimatou	Lecturer	In service
26.	BEBOY EDJENGUELE Sara Nathalie	Lecturer	In service

27.	DAKOLE DABOY Charles	Lecturer	In service
28.	DONGMO LEKAGNE Joseph Blaise	Lecturer	In service
29.	FONKOUA Martin	Lecturer	In service
30.	FOUPOUAPOUOGNIGNI Yacouba	Lecturer	In service
31.	KOUOH ELOMBO Ferdinand	Lecturer	In service
32.	MANANGA Marlyse Josephine	Lecturer	In service
33.	OWONA AYISSI Vincent Brice	Lecturer	In service
34.	Palmer MASUMBE NETONGO	Lecturer	In service
35.	PECHANGOU NSANGOU Sylvain	Lecturer	In service
36.	WILFRED ANGIE ABIA	Lecturer	In service
37.	BAKWO BASSOGOG Christian Bernard	Assistant	In service
38.	ELLA Son Armand	Assistant	In service
39.	EYENGA Eliane Flore	Assistant	In service
40.	MADIESSE KEMGNE Eugenie Aimee	Assistant	In service
41.	MANJIA NJIKAM Jacqueline	Assistant	In service
42.	MBOUCHE FANMOE Marceline Joëlle	Assistant	In service
43.	WOGUIA Alice Louise	Assistant	In service

2- DEPARTMENT OF ANIMAL BIOLOGY AND PHYSIOLOGY (BPA) (52)			
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2.	BILONG BILONG Charles-Felix	Professor	*Head of Department*
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4.	DJIETO LORDON Champlain	Professor	In service
5.	DZEUFIET DJOMENI Paul Désiré	Professor	In service
6.	ESSOMBA born NTSAMA MBALA	Professor	*CD and Vice Dean/FMSB/UYI*
7.	FOMENA Abraham	Professor	In service
8.	KEKEUNOU Sevilor	Professor	In service
9.	NJAMEN Dieudonne	Professor	In service
10.	NJIOKOU Flobert	Professor	In service
11.	NOLA Moses	Professor	In service
12.	TAN Paul VERNYUY	Professor	In service
13.	TCHUEM TCHUENTE Louis Albert	Professor	*IP Service / Coord.Progr ./ MINSANTE*
14.	ZEBAZE TOGOUET Serge Hubert	Professor	In service
15.	ALENE Desiré Chantal	Associate Professor	*Vice Dean/ Unit Ebolowa*
16.	BILANDA Danielle Claude	Associate Professor	In service
17.	DJIOGUE Sefirin	Associate Professor	In service
18.	GOUNOUE KAMKUMO Raceline epse FOTSING	Associate Professor	In service
19.	JATSA BOUKENG Ermine epse MEGAPTCHE	Associate Professor	In service
20.	LEKEUFACK FOLEFACK Guy B.	Associate Professor	In service
21.	MAHOB Raymond Joseph	Associate Professor	In service
22.	MBENOUN MASSE Paul Serge	Associate Professor	In service
23.	MEGNEKOU Rosette	Associate Professor	In service

24.	MOUNGANG Luciane Marlyse	Associate Professor	In service
25.	NOAH EWOTI Olive Vivien	Associate Professor	In service
26.	MONY Ruth epse NTONE	Associate Professor	In service
27.	NGUEGUIM TSOFACK Florence	Associate Professor	In service
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29.	TAMSA ARFAO Antoine	Associate Professor	In service
30.	TOMBI Jeannette	Associate Professor	In service
31.	ATSAMO Albert Donatien	Lecturer	In service
32.	BASSOCK BAYIHA Etienne Didier	Lecturer	In service
33.	ETEME ENAMA Serge	Lecturer	In service
34.	FEUGANG YOUMSSI François	Lecturer	In service
35.	FOKAM Alvine Christelle Epse KENGNE	Lecturer	In service
36.	GONWOUO NONO Legrand	Lecturer	In service
37.	KANDEDA KAVAYE Antoine	Lecturer	In service
38.	KOGA MANG DOBARA	Lecturer	In service
39.	LEME BANOCK Lucie	Lecturer	In service
40.	MAPON NSANGOU Hindu	Lecturer	In service
41.	METCHI DONFACK MIREILLE FLAURE EPSE GHOUMO	Lecturer	In service
42.	MVEYO NDANKEU Yves Patrick	Lecturer	In service
43.	NGOUATEU KENFACK Omer Baby	Lecturer	In service
44.	NJUA Clarisse YAFI	Lecturer	*Head Div. Ute Bamenda*
45.	NWANE Philippe Welcome	Lecturer	In service
46.	TADU Zephyrin	Lecturer	In service
47.	YEDE	Lecturer	In service
48.	YOUNOUSSA BLADE	Lecturer	In service
49.	AMBADA NDZENGUE GEORGIA ELNA	Assistant	In service
50.	KODJOM WANCHE Jacguy Joyce	Assistant	In service
51.	NDENGUE Jean De Matha	Assistant	In service
52.	ZEMO GAMO Franklin	Assistant	In service

3- DEPARTMENT OF PLANT BIOLOGY AND PHYSIOLOGY (BPV) (34)			
1.	AMBANG Zacchaeus	Professor	*Head of Department*
2.	DJOCGOUE Pierre Francois	Professor	In service
3.	MBOLO Marie	Professor	In service
4.	MOSSEBO Dominique Claude	Professor	In service
5.	YOUMBI Emmanuel	Professor	In service
6.	ZAPFACK Louis	Professor	In service
7.	ANGONI Hyacinth	Associate Professor	In service
8.	BIYE Elvire Hortense	Associate Professor	In service
9.	MAHBOU SOMO TOUKAM. Gabriel	Associate Professor	In service
10.	MALA Armand William	Associate Professor	In service
11.	MBARGA BINDZI Marie Alain	Associate Professor	*DAAC / Uté Dla*
12.	NDONGO BEKOLO	Associate Professor	In service
13.	NGALLE Hermine BILLE	Associate Professor	In service
14.	NGODO MELINGUI Jean Baptiste	Associate Professor	In service
15.	NGONKEU MAGAPTCHE Eddy L.	Associate Professor	*CT / MINRESI*

16.	TONFACK Libert Brice	Associate Professor	In service
17.	TSOATA Isaiah	Associate Professor	In service
18.	ONANA JEAN MICHEL	Associate Professor	In service
19.	DJEUANI Astride Carole	Lecturer	In service
20.	GONMADGE CHRISTELLE	Lecturer	In service
21.	MAFFO MAFFO Nicole Liliane	Lecturer	In service
22.	NNANGA MEBENGA Ruth Laure	Lecturer	In service
23.	NOUKEU KOUAKAM Armelle	Lecturer	In service
24.	NSOM ZAMBO EPSE PIAL ANNIE CLAUDE	Lecturer	*On secondment/UNESCO MALI*
25.	GODSWILL NTSOMBOH NTSEFONG	Lecturer	In service
26.	KABELONG BANAHO Louis-Paul-Roger	Lecturer	In service
27.	KONO Leon Dieudonne	Lecturer	In service
28.	LIBALAH Moses BAKONCK	Lecturer	In service
29.	LIKENG-LI-NGUE Benoit C	Lecturer	In service
30.	TAEDOUNG Evariste Hermann	Lecturer	In service
31.	TEMEGNE NONO Carine	Lecturer	In service
32.	MANGA NDJAGA JUDE	Assistant	In service
33.	DIDA LONTSI Sylvere Landry	Assistant	In service
34.	METSEBING Blondo-Pascal	Assistant	In service

4- DEPARTMENT OF INORGANIC CHEMISTRY (CI) (28)			
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2.	NANSEU NJIKI Charles Péguy	Professor	In service
3.	NDIFON Peter TEKE	Professor	*CT MINRESI*
4.	NENWA Justin	Professor	In service
5.	NGAMENI Emmanuel	Professor	*Dean FS Univ. Ngaoundere*
6.	NGOMO Horace MANGA	Professor	*Vice Chancellor /UB*
7.	NJOYA Dayirou	Professor	In service
8.	ACAYANKA Elie	Associate Professor	In service
9.	EMADAK Alphonse	Associate Professor	In service
10	KAMGANG YOUBI Georges	Associate Professor	In service
11	KEMMEGNE MBOUGUEM Jean C.	Associate Professor	In service
12	KENNE DEDZO GUSTAVE	Associate Professor	In service
13	MBEY Jean Aime	Associate Professor	In service
14	NDI NSAMI Julius	Associate Professor	*Head of Department*
15	NEBAH Born NDOSIRI Bridget NDOYE	Associate Professor	*Senator/SENATE*
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17	NYAMEN Linda Dyorisse	Associate Professor	In service
18	PABOUDAM GBAMBIE AWAWOU	Associate Professor	In service
19	TCHAKOUTE KOUAMO Herve	Associate Professor	In service
20	BELIBI BELIBI Placide Désiré	Associate Professor	*Head of Service/ ENS Bertoua*

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22.	KOUOTOU DAOUDA	Associate Professor	In service
23.	MAKON Thomas Beauregard	Lecturer	In service
24.	NCHIMI NONO KATIA	Lecturer	In service
25.	NJANKWA NJABONG N. Eric	Lecturer	In service
26.	PATOUOSSA ISSOFA	Lecturer	In service
27.	SIEWE Jean Mermoz	Lecturer	In service
28.	BOYOM TATCHEMO Franck W.	Assistant	In service

5- DEPARTMENT OF ORGANIC CHEMISTRY (CO) (37)			
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3.	NGOUELA Silvere Augustin	Professor	*Head of UDS Department*
4.	PEGNYEMB Dieudonne Emmanuel	Professor	*Director/ MINESUP/ Head of Department*
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6.	MBAZOA born DJAMA Céline	Professor	In service
7.	AMBASSA Pants	Associate Professor	In service
8.	EYONG Kenneth OBEN	Associate Professor	In service
9.	FOTSO WABO Ghislain	Associate Professor	In service
10	KAMTO Eutrophe Le Doux	Associate Professor	In service
11	KENMOGNE Marguerite	Associate Professor	In service
12	KEUMEDJIO Felix	Associate Professor	In service
13	KOUAM Jacques	Associate Professor	In service
14	MKOUNGA Pierre	Associate Professor	In service
15	MVOT AKAK CARINE	Associate Professor	In service
16	NGO MBING Josephine	Associate Professor	*Head of Cell MINRESI*
17	NGONO BIKOBO Dominique Serge	Associate Professor	*CEA / MINESUP*
18	NOTE LOUGBOT Olivier Placide	Associate Professor	*DAAC/ Uté Bertoua*
19	NOUNGOUE TCHAMO Diderot	Associate Professor	In service
20	TABOPDA KUATE Turibio	Associate Professor	In service
21	TAGATSING FOTSING Mauritius	Associate Professor	In service
22	TCHOUANKEU Jean-Claude	Associate Professor	*Dean /FS/ UYI*
23	YANKEP Emmanuel	Associate Professor	In service
24	ZONDEGOUMBA Ernestine	Associate Professor	In service
25.	MESSI Angelique Nicolas	Lecturer	In service
26.	NGNINTEDO Dominica	Lecturer	In service
27.	NGOMO Orleans	Lecturer	In service
28.	NONO NONO Eric Carly	Lecturer	In service
29.	OUAHOUO WACHE Blandine M.	Lecturer	In service
30.	OUETE NANTCHOUANG Judith Laure	Lecturer	In service
31.	SIELINOU TEDJON Valerie	Lecturer	In service

32.	TCHAMGUE Joseph	Lecturer	In service
33.	TSAFFACK Mauritius	Lecturer	In service
34.	TSAMO TONTSA Armelle	Lecturer	In service
35.	TSEMEUGNE Joseph	Lecturer	In service
36.	MUNVERA MFIFEN Aristide	Assistant	In service
37.	NDOGO ETEME Olivier	Assistant	In service

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1.	ATSA ETOUNDI Roger	Professor	*Head of Division/ MINESUP*
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3.	NDOUNDAM Rene	Associate Professor	In service
4.	TSOPZE Norbert	Associate Professor	In service
5.	ABESSOLO ALO'O Gislain	Lecturer	*Head of Unit /MINFOPRA*
6.	AMINOU HALIDOU	Lecturer	*Head of Department*
7.	DJAM Xaviera YOUH - KIMBI	Lecturer	In service
8.	DOMGA KOMGUEM Rodrigue	Lecturer	In service
9.	EBELE Serge Alain	Lecturer	In service
10.	HAMZA Adamou	Lecturer	In service
11.	JIOMEKONG AZANZI Fidel	Lecturer	In service
12.	KOUOKAM KOUOKAM AND OTHERS	Lecturer	In service
13.	MELATAGIA YONTA Paulin	Lecturer	In service
14.	MESSI NGUELE Thomas	Lecturer	In service
15.	MONTHE DJIADEU Valery M.	Lecturer	In service
16.	NZEKON NZEKO'O ARMEL JACQUES	Lecturer	In service
17.	OLLE OLLE Daniel Claude Georges Delort	Lecturer	*Deputy/ Director ENSET Ebolowa*
18.	TAPAMO Hyppolite	Lecturer	In service
19.	BAYEM Jacques Narcisse	Assistant	In service
20.	EKODECK Stéphane Gael Raymond	Assistant	In service
21.	MAKEMBE. S. Oswald	Assistant	*CUTI Director*
22.	NKONDOCK. MID. BAHANACK.N.	Assistant	In service

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6.	NOUNDJEU Stone	Associate Professor	*Head of Programs & Diplomas/FS/UYI*
7.	TAKAM SOH Patrice	Associate Professor	In service
8.	TCHAPNDA NJABO Sophonie B.	Associate Professor	*Director/AIMS Rwanda*

9.	TCHOUNDJA Edgar Landry	Associate Professor	In service
10	AGHOUKENG JIOFACK Jean Gérard	Lecturer	*Head of Unit MINEPAT*
11	BOGSO ANTOINE Marie	Lecturer	In service
12	CHENDJOU Gilbert	Lecturer	In service
13	DJIADEU NGAHA Michel	Lecturer	In service
14	DOUANLA YONTA Herman	Lecturer	In service
15	Maxime Armand	Lecturer	In service
16	LOUMNGAM KAMGA Victor	Lecturer	In service
17	MBAKOP Guy Merlin	Lecturer	In service
18	MBATAKOU Solomon Joseph	Lecturer	In service
19	MENGUE MENGUE David Joel	Lecturer	*Head of Department /ENS University of Ebolowa*
20	MBIAKOP Hilaire George	Lecturer	In service
21	NGUEFACK Bernard	Lecturer	In service
22	NIMPA PEFOUKEU Roman	Lecturer	In service
23	OGADOA AMASSAYOGA	Lecturer	In service
24	POLA DOUNDOU Emmanuel	Lecturer	*Internship*
25	TCHEUTIA Daniel Duviol	Lecturer	In service
26	TETSADJIO TCHILEPECK Mr. Eric.	Lecturer	In service

27	BITYE MVONDO Esther Claudine	Assistant	In service
28	FOKAM Jean-Marcel	Assistant	In service
29	GUIDZAVAI KOUCHERE Albert	Assistant	In service
30	MANN MANYOMBE Martin Luther	Assistant	In service
31	MEFENZA NOUNTU Thiery	Assistant	In service
32	NYOUMBI DLEUNA Christelle	Assistant	In service
33	TENKEU JEUFACK Yannick Léa	Assistant	In service

8- DEPARTMENT OF MICROBIOLOGY (MIB) (24)			
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2.	NYEGUE Maximilian Ascension	Professor	*VICE-DEAN / DHSE*
3.	ASSAM ASSAM John Paul	Associate Professor	In service
4.	BOUGNOM Blaise Pascal	Associate Professor	In service
5.	BOYOMO ONANA	Associate Professor	In service
6.	KOUITCHEU MABEKU Epse KOUAM Laure Brigitte	Associate Professor	In service
7.	RIWOM Sara Honorine	Associate Professor	In service
8.	NJIKI BIKOI Jacky	Associate Professor	In service

9.	SADO KAMDEM Sylvain Leroy	Associate Professor	In service
10	ESSONO Damien Marie	Lecturer	In service
11	LAMYE Glory MOH	Lecturer	In service
12	MEYIN A EBONG Solange	Lecturer	In service
13	MONI NDEDI Esther Del Florence	Lecturer	In service
14	NKOUDOU ZE Nardis	Lecturer	In service
15	TAMATCHO KWEYANG Blandine Pulchérie	Lecturer	In service
16	TCHIKOUA Roger	Lecturer	*Head of Education Department*
17	TOBOLBAI Richard	Lecturer	In service
18	NKOUE TONG Abraham	Assistant	In service
19	SAKE NGANE Carole Stéphanie	Assistant	In service
20	EZO'O MENGO Fabrice Telesfor	Assistant	In service
21	EHETH Jean Samuel	Assistant	In service
22	MAYI Marie Paule Audrey	Assistant	In service
23	NGOUENAM Romial Joel	Assistant	In service
24	NJAPNDOUNKE Bilkissou	Assistant	In service

9. DEPARTMENT OF PYSICS (PHY) (43)			
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2.	DJUIDJE KENMOE marries ALOYEM	Professor	In service
3.	EKOBENA FOUDA Henri Paul	Professor	*Vice Chancellor. Ute Ngaoundere*
4.	ESSIMBI ZOBO Bernard	Professor	In service
5.	HONA Jacques	Professor	In service
6.	NANA ENGO Serge Guy	Professor	In service
7.	NANA NBENDJO Blaise	Professor	In service
8.	NDJAKA Jean Marie Bienvenu	Professor	*Head of Department*
9.	NJANDJOCK NOUCK Philippe	Professor	In service
10.	NOUAYOU Robert	Professor	In service
11.	SAIDOU	Professor	*Head of Center/IRGM/MINRESI*
12.	TABOD Charles TABOD	Professor	*Dean FSUniv / Bda*
13.	TCHAWOUA Clement	Professor	In service
14.	WOAFO Paul	Professor	In service
15.	ZEKENG Serge Sylvain	Professor	In service
16.	BIYA MOTTO Frederic	Associate Professor	*DG/HYDRO Mekin*
17.	BODO Bertrand	Associate Professor	In service
18.	ENYEGUE A NYAM épse BELINGA	Associate Professor	In service
19.	EYEBE FOUDA Jean sire	Associate Professor	In service
20.	FEWO Serge Ibraïd	Associate Professor	In service
21.	MBINACK Clement	Associate Professor	In service

22.	MBONO SAMBA Yves Christian U.	Associate Professor	In service
23.	MELI'I Joelle Larissa	Associate Professor	In service
24.	MVOGO ALAIN	Associate Professor	In service
25.	NDOP Joseph	Associate Professor	In service
26.	SIEWE SIEWE Martin	Associate Professor	In service
27.	SIMO Elie	Associate Professor	In service
28.	VONDOU Derbetini Appolinaire	Associate Professor	In service
29.	WAKATA born BEYA Annie Sylvie	Associate Professor	*Director/ENS/UYI*
30.	WOULACHE Rosalie Laure	Associate Professor	*On internship since February 2023*
31.	ABDOURAHIMI	Lecturer	In service
32.	AYISSI EYEBE Guy François Valérie	Lecturer	In service
33.	CHAMANI Romeo	Lecturer	In service
34.	DJIOTANG TCHOTCHOU Lucie Angennes	Lecturer	In service
35.	EDONGUE HERVAIS	Lecturer	In service
36.	FOUEJIO David	Lecturer	*Head of Cell . MINADER*
37.	KAMENI NEMATCHOUA Modest	Lecturer	In service
38.	LAMARA Mauritius	Lecturer	In service
39.	OTTOU ABE Martin Thierry	Lecturer	*Director Reagents Production Unit/IMPM*
40.	TEYOU NGOUPO Ariel	Lecturer	In service
41.	WANDJI NYAMSI William	Lecturer	In service
42.	NGA ONGODO Dieudonne	Assistant	In service
43.	SOUFFO TAGUEU Merimé	Assistant	In service

10- DEPARTMENT OF EARTH SCIENCES (ST) (42)			
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2.	NDAM NGOUPAYOU Jules-Remy	Professor	In service
3.	NDJIGUI Paul-Desire	Professor	*Head of Department*
4.	NGOS III Simon	Professor	In service
5.	NKOUMBOU Charles	Professor	In service
6.	NZENTI Jean-Paul	Professor	In service
7.	ONANA Vincent Laurent	Professor	*Head of Department/ Unit. Ebolowa.*
8.	YENE ATANGANA Joseph Q.	Professor	*Chief Div. /MINTP*
9.	ABOSSOLO Né ANGUE Monique	Associate Professor	*Vice-Dean / DRC*
10.	BISSO Dieudonne	Associate Professor	In service
11.	EKOMANE Emile	Associate Professor	*Head Div./ Uté Ebolowa*
12.	Elise SABABA	Associate Professor	In service
13.	FUH Calistus Gentry	Associate Professor	*Dry. of State /MINMIDT*
14.	GANO Sylvester	Associate Professor	In service
15.	GHOGOMU Richard TANWI	Associate Professor	*Head of Div. / Uté Bertoua*

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20.	NJILAH Isaac KONFOR	Associate Professor	In service
21.	NYECK Bruno	Associate Professor	In service
22.	TCHAKOUNTE Jacqueline joins NUMBEM	Associate Professor	*Head of Cell /MINRESI*
23.	TCHOUANKOUE Jean-Pierre	Associate Professor	In service
24.	TEMGA Jean Pierre	Associate Professor	In service
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27.	BEKOA Etienne	Lecturer	In service
28.	ESSONO Jean	Lecturer	In service
29.	EYONG John TAKEM	Lecturer	In service
30.	MAMDEM TAMTO Lionelle Estelle, wife BITOM	Lecturer	In service
31.	MBESSE Cecile Olive	Lecturer	In service
32.	METANG Victor	Lecturer	In service
33.	MINYEM Dieudonne	Lecturer	*Chief Serv ./ Uté Maroua*
34.	NGO BELNOUN Pink Christmas	Lecturer	In service
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36.	NTSAMA ATANGANA Jacqueline	Lecturer	In service
37.	TCHAPTCHET TCHATO De P.	Lecturer	In service
38.	TEHNA Nathanael	Lecturer	In service
39.	FEUMBA Roger	Lecturer	In service
40.	MBANGA NYOBE Jules	Lecturer	In service
41.	KOAH NA LEBOGO P.Serge	Assistant	In service
42.	NGO'O ZE ARNAUD	Assistant	In service
43.	TENE DJOUKAM Joëlle Flore, wife KOUANKAP NONO	Assistant	In service

Numerical breakdown of teachers from the Faculty of Science of the University of Yaoundé 1

	NUMBER OF TEACHERS				
DEPARTMENT	**Professors**	**Associate Professors**	**Lecturers**	**Assistants**	**Total**
BCH	8 (01)	15 (11)	13 (03)	7 (05)	**43 (20)**
EPS	14 (01)	16 (09)	18 (04)	4 (02)	**52 (16)**
GVP	6 (01)	12 (02)	13 (07)	3 (00)	**34 (10)**
THIS	7 (01)	15 (04)	5 (01)	1 (00)	**28 (06)**
CO	6 (01)	18 (04)	11 (04)	2 (00)	**37 (09)**
IN	2 (00)	2 (00)	14 (01)	4 (00)	**22 (01)**
MAST	1 (00)	8 (00)	17 (01)	7 (02)	**33 (03)**
MIBs	2 (01)	7 (03)	8 (04)	7 (02)	**24 (10)**
PHY	15 (01)	15 (04)	11 (01)	2 (00)	**43 (06)**
ST	8 (00)	17 (03)	15 (04)	3 (01)	**43 (08)**
Total	**69 (07)**	**125 (40)**	**125 (30)**	**40 (12)**	**359 (89)**

For a total of	**359 (89)** including:
- Professors	**69 (07)**
- Associate Professors	**125 (40)**
- Lecturers	**125 (30)**
- Assistants	**40 (12)**

( ) = Number of Women **89**

Dedication

I dedicate this thesis to my precious wife OMA Thérèse Diane, my daughters NDIFOR D. Godsfaith and FOMENA D. Noémie, and to my guardians Mr. FOPA FOMENA Jérôme, Ms. FOPA KUETE Valentine Laure.

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List of abbreviations

AM	Ante Meridien
PM	Post Meridien
°C	Degree Celsius
CITES	International Convention for the Trade of Endangered Species
COTCO	Cameroon Oil Transportation Company
WCS	Wildlife Conservation Society
IUCN	International Union for Nature Conservation
LAGA	Last Great Ape Organization
EIA	Environmental Investigation Agency
MINFOF	Cameroon Ministry of Forestry and Wildlife
EDC	Electricity Development Corporation
DDNP/PNDD	Deng-Deng National Park/ *Parc National de Deng Deng*
GPS	Global Positioning System
GP	Giant Pangolin
WBP/PVB	White-bellied pangolin/ *Pangolin à ventre blanc*
BBP/PVN	Black-bellied pangolin/ *Pangolin à ventre noir*
Gb.	Gigabyte
SE	Sampling Effort
LEK	Local Ecological Knowledge
MDNP/PNMD	Mpem et Djim National Park/ *Parc National de Mpem et Djim*
GVC	Global Village Cameroon
SPSS	Statistical Package of the Social Science
QGIS	Quantum Geographical Information System
FSST	Feeding site on standing tree
GFS	Ground feeding sites
LB	Living burrow
FB	Feeding burrow
DTWT	Decaying trunks with termites
DTWtT	Decaying trunks without termites
TM	Termite mound
TH	Tree hollow
GF	Gallery Forest
NPF	Near Primary Forest
WS	Woodland Savanna
Sl.	Saltworks
GS	Grassland Savanna
Sw.	Swamp
SF	Secondary Forest

Definitions of concepts

Local ecological knowledge (LEK) is usually referring to the environmentally related knowledge acquired over the lifetime of individuals developed through interactions with the natural environment (Gilchrist *et al*., 2005).

Habitat refers to the environment of an organism, the place where it is usually found (Tagliapietra & Sigovin, 2010; Krausman, 1999). Habitat describes the conditions surrounding the location of an animal (Morrison, 2001). Globally, habitat is a set of resources and conditions necessary for sustained occupancy (time considered) of an area by an organism (Hall *et al*., 1997; Morrison & Mathewson, 2015) or the type of place where an animal normally lives or, more specifically, the collection of resources and conditions necessary for its occupancy (Garshelis, 2000).

Selection is defined as the process by which a resource is chosen (Manly *et al*., 2002).

S**election ratio or forage ratio** (Hess & Swartz, 1940) is the proportional resource item use divided by the proportional availability of each resource item (Manly *et al*., 2002).

Habitat selection is referring to the rules used by organisms to choose among patches or habitats that differ in one or more variables such as food availability (Johnson, 1980).

Preference is the probability that a given resource will be selected among many available in equal proportion (Manly *et al*., 2002).

Habitat preference defined the process where a habitat is most likely chosen by a species given the opportunity or which habitat the species is best suited (Morrison & Mathewson, 2015).

An independent photographic event is defined by McPhee (2015) as the total number of photos or videos recorded of each species captured within one hour, and separated by at least one hour. It is also defined as two consecutive events of different species or consecutive events of two different individuals and finally consecutive events of the same individual within 1 hour (Tobler *et al*., 2008; Wearn *et al*., 2013).

Sampling effort (SE) is the accumulated total number of 24-hour days that all camera traps installed in the survey areas were on and functional, estimated between the first and last photo taken (McPhee, 2015).

A camera trap night/day or 24-hour days is 24 hours that a camera trap installed in the survey area was on and functional (McPhee, 2015).

Feeding behavior is defined as any action of an animal that is directed toward the procurement of nutrients (Carss, 1995).

Feeding ecology is defined as the processes which determine the general diet and will include various factors such as prey selection (Carss, 1995).

Diet composition is defined as the quantity and quality of the food which can satisfy the life function of an animal organism. It is also the kind and amount of food and drinks regularly provided or consumed or prescribed for a person or animal for a special reason; a regimen of eating and drinking sparingly to reduce one's weight going on a diet (Johnson, 1980).

The following definition of concepts are from this study and some are published in Simo *et al.* (2020).

Ground Feeding sites (GFS) is defined as potential pangolin feeding sites on the ground as indicated by soil excavations of different ages (fresh to very old). The diameter of this sign ranged from 5 to 10 cm.

Living burrows (LB) are holes in the ground with a diameter wide more than 40 cm; potential ground burrows were holes dug in the ground at the base of trees, exhibiting multiple entrances adjacent to tree roots and ranging from 20 to 30cm in diameter (Simo *et al*., 2020).

Tree hollow (TH) or cavities in trees are defined as tree cavities indicated by holes in the central axis of very old fallen trunks with one or two entrances at one or both ends of the trunk (Simo *et al*., 2020).

Feeding burrow (FB) are burrows in the ground with a diameter radius less than 20 cm potentially dug by giant pangolin or aardvark to search for food.

Decaying trunks with termites (DTWT) are downed death trees, showing signs of animal activities on the upper side and termite individuals, targeted as a possible travel route and feeding site (Simo *et al*., 2020).

Decaying trunks without termites (**DTWtT)** are downed death trees, showing signs of animal activities on the upper side without evidence of termite, targeted as possible travel routes.

Feeding sites on standing trees (FSST) are standing death trees showing microsites with multiple scratches either along the length of the trunk or at the base of the trunk.

Termite mound (TM) is a large, often conical mound of soil and termite feces built as a nest by a colony of termites of certain tropical species. If the mound is above the ground, on the tree, it is called a termite tree nest or epigeal tree nest.

Abstract

Pangolins are an unusual group of mammals covered by keratinized scales. They are widely threatened with extinction throughout their home range. Pangolins currently are the most highly trafficked mammal by volume in the world. To better understand the ecology of wild Central African pangolins and to help conserve them, community surveys were undertaken to assess local people's perception of pangolins, and field ecological surveys were carried out on habitat and food preferences and other aspects of the feeding behavior of pangolins in two forest-savanna protected areas in Cameroon, Deng Deng National Park (hereafter, DDNP) and Mpem et Djim National Park (hereafter, MDNP). A questionnaire survey was carried out between March 8–16th, 2018 at DDNP, and from August 21 to September 3, 2018, at MDNP. Camera-trap survey and insect prey sampling were carried out from April 2018 to April 2020. Overall, 376 residents, selected in 20 villages around these protected areas, through a snowball sampling technique were interviewed using semi-structured questionnaires. The physiognomic of the vegetation formations of both parks were characterized. Camera traps were installed in major dry and rainy seasons to confirm the presence of pangolins in the study localities and to document their feeding behavior. The ants and termites, and the potential pangolin preys were collected in different vegetation formations through pitfall and bait traps and hand-sampling technics respectively. Two fresh scat samples from parks and 13 stomach contents of white-bellied pangolin and one of giant pangolin from villagers living around the parks were collected and analyzed. Giant pangolin, *Smutsia gigantea*, hereafter GP and white-bellied pangolin *Phataginus tricuspis* hereafter WBP were well-known by most of the respondents in the study areas. The black-bellied pangolin *Phataginus tetradactyla*, hereafter BBP was poorly known and frequently grouped with WBP verbally as *petit pangolin* but distinguish morphologically and culturally. Respondents reported that GPs were commonly found in savanna burrows, while the WBPs were often seen in the forest, crossing fallen logs and on trees. The BBPs were reportedly sighted mostly on rattan palms in both forest and savanna swamp habitats. Most of the respondents reported that pangolins feed predominantly on ants and termites. Seven main different types of vegetation formations were described in DDNP and MDNP, including near primary forest, secondary forest, gallery forest, swamp, woodland savanna, grassland savanna, and saltwork. From camera traps, 5,889 independent photographic events of large to medium size mammals were recorded, including 355 photographic events of white-bellied pangolins in six different habitat types. A total of 32 events of giant pangolins were recorded in four different habitat types. No evidence of black-bellied pangolin presence was recorded during the survey period. The trapping rate of GP in both national parks was relatively lower with 0.53% recorded in MDNP and 0.32% in DDNP. WBP trapping rate (3.55%) was relatively higher in MDNP than in DDNP (2.75%)

with no significant difference between both protected areas. Giant pangolin activities mostly observed, including passing by burrows (7.36%) and foraging (2.72%) were not significantly different between the rainy and dry seasons. White-bellied pangolin activities mostly include eating (30.81%), foraging (24.71%), and passing (43.6%). WBP feeding was more often observed during the rainy season (31.10%) than in the dry season. The probability to detect giant pangolins in gallery forest (Bi=0.567), grassland savanna (Bi=0.222), and woodland savanna (Bi=0.183) was higher than in other habitats. The probability to detect WBPs in swamps (Bi=0.555) was higher than in other habitat types. A total of 107 species of ants, 29 genera, and six subfamilies were recorded in both parks from a sample of 14, 093 individuals. A total of 89 species of termites comprising 33 genera and 10 subfamilies were recorded in both parks from a sample of 56,798 individuals. Stomach content samples from 13 white-bellied pangolin specimens contained 165,161 individuals of invertebrates including 165,000 Arthropoda belonging to six Orders, mostly Hymenoptera (60.34%) and Blattodea (39.65%). Overall, 144 insect species were identified in the stomachs of 13 WBP individuals, including 39 termite species and 105 ant species. The mean abundance of ants and termites consumed was significantly higher during the dry season. Among WBP termite preys, *Macrotermes bellicosus* likelihood of selection was roughly two times greater than all the other prey species. *Crematogaster acis*, *Pheidole minima*, and *Crematogaster* (*Oxygyne*) sp. 2 were eaten more often than other ant preys. For giant pangolins, termite preys were less than 30% of the total invertebrates recorded in both scat and stomach contents compared to 70% for ants. *Pseudacanthotermes militaris* was the most abundant termite species in the diet compositions of giant pangolins examined. Among the giant pangolin preys, *Cataulacus weissi* and *Camponotus brutus* selection likelihoods were the highest among all prey species. This study enhances the understanding of pangolin life history through their habitat and prey selections, feeding behavior, and some ethnozoological aspects. Further investigations should be carried out to assess factor influencing feeding behavior, habitat preference, the ecological traits of prey species and the variation of the different types of pangolin preys by sex and age of individual but also focus on assessing the biochemical composition and nutritional value of pangolin prey insects to offer food substitutes for husbandry and reintroduction.

Keywords: Pholidota, pangolin, forest-savanna ecotone, feeding behavior, diet composition, habitat and prey preferences, local ecological knowledge, Cameroon

Résumé

Les pangolins forment un groupe inhabituel de mammifères menacés d'extinction dans toutes leurs aires de répartition en raison de la demande croissante de leurs écailles pour la médecine traditionnelle asiatique. Afin de mieux comprendre l'écologie des pangolins et contribuer efficacement à leur conservation, la perception du pangolin a été évaluée chez les populations des villages riverains de deux aires protégées (le Parc National de Mpem et Djim (PNMD) et le Parc National de Deng Deng (PNDD)) ainsi que leurs préférences en matière d'habitat, d'alimentation et le comportement alimentaire des pangolins. Une enquête a été menée dans la période allant du 8 au 16 mars dans le PNDD, et du 21 août au 3 septembre 2018 dans le PNMD. L'étude de camera-pièges et la collecte des insectes proies ont été menées d'avril 2018 à avril 2020. Au total, 376 habitants, sélectionnés dans 20 villages autour de ces aires protégées, par la méthode boule de neige ont été interrogés à l'aide des questionnaires semi-structurés. La physionomie des formations végétales des deux parcs a été caractérisée. Les caméras pièges ont été installées pendant les grandes saison sèche et grande saison pluvieuse pour étudier le comportement des pangolins dans les localités d'étude. Les fourmis et les termites, proies potentielles des pangolins, ont été collectées dans différentes formations végétales, respectivement à l'aide des techniques de *pitfalls* et d'appâts et de capture manuelle. Pour identifier les proies réelles des pangolins, deux échantillons d'excréments frais provenant des habitats de ces espèces et 14 contenus stomacaux des pangolins morts destinés la consommation locale ont été collectés chez les populations locales pour analyse au laboratoire. D'après les résultats de l'enquête, les populations ont une bonne connaissance du pangolin à ventre blanc *Phataginus tricuspis* ci-après PVB et du pangolin géant *Smutsia gigantea*, ci-après PG. Le pangolin à ventre noir *Phataginus tetradactyla*, ci-après PVN était moins connu des populations et fréquemment associé au PVB sous le nom de petit pangolin. Ces populations ont une bonne connaissance du régime alimentaire des pangolins ainsi que de leurs habitats préférentiels dans la forêt et la savane. Elles ont aussi cité des sites spécifiques où les pangolins sont souvent trouvés autant dans la forêt que dans la savane. Au total, sept principaux types de formations végétales ont été décrits dans les deux aires protégées, à savoir la forêt presque primaire, la forêt secondaire, les galeries forestières, les marécages, la savane boisée, la savane herbeuse et les salines. A partir des caméras pièges, 5 889 événements photographiques indépendants de mammifères ont été enregistrés, dont 355 événements photographiques de pangolin à ventre blanc dans six types d'habitats différents. Au total, 32 événements de pangolin géant ont été enregistrés dans quatre types d'habitats différents. Aucun signe de présence de pangolin à ventre noir n'a été enregistré pendant la période d'étude. Le taux de piégeage du pangolin géant dans les deux parcs nationaux était faible, soit 0,53% au PNMD et 0,32% au PNDD. Le taux de piégeage du pangolin à ventre blanc (3,55%)

était relativement plus élevé dans le PNMD que dans le PNDD (2,7 %). Les activités du pangolin géant étaient principalement le passage près des terriers (7,36%) et le fourragement (2,72%). Les activités du pangolin à ventre blanc ont été principalement la nutrition (30,81%), le fourragement (24,71%) et le passage (43,6%). La probabilité de détection du pangolin géant a été plus élevée dans la galerie forestière (Bi=0,567) alors que celle du pangolin à ventre blanc a été plus élevée dans le marécage (Bi=0,555). Concernant les proies potentielles, 14 individus de fourmis ont été collectés, répartis en 107 espèces, 29 genres et six sous-familles. Alors que, 56798 individus de termites répartis en 89 espèces, 33 genres et neuf sous-familles ont été enregistrés dans les deux parcs. Concernant les proies réelles, 165 000 arthropodes appartenant à six ordres, dominés par les Hymenoptera (60,34%) et les Blattodea (39,65%), ont été recensés dans 13 contenus stomacaux chez le pangolin à ventre blanc. Globalement 144 espèces d'insectes consommées par le pangolin à ventre blanc ont été identifiées (dont 39 espèces de termites et 105 espèces de fourmis) réparties en trois familles, 12 sous familles et 42 genres. L'abondance moyenne des fourmis et termites consommées a été significativement plus élevée pendant la saison sèche. Parmi les termites, *Nasutitermes arborum* a été l'espèce de termite la plus abondante dans le régime alimentaire du pangolin à ventre blanc. La probabilité de sélection de *Macrotermes bellicosus* par le pangolin à ventre blanc a été d'environ deux fois supérieure à celle de toutes les autres espèces proies. Concernant le pangolin géant, les fourmis ont représenté 70% contre de 30% de termites consommée. Parmi les fourmis, les probabilités de sélection de *Cataulacus weissi* et *Camponotus brutus* ont été d'environ deux fois supérieures à celle de toutes les autres proies. Parmi les termites, *Pseudacanthotermes militaris* a été l'espèce la plus abondante dans le régime alimentaire du pangolin géant. La présente étude améliore la compréhension des traits de vie des pangolins, plus leur sélection de l'habitat et des proies, le comportement alimentaire et certains aspects ethno zoologiques. Des investigations supplémentaires devraient être menées pour évaluer et mieux comprendre le comportement de nutrition, les facteurs influençant la préférence d'habitat, les caractéristiques écologiques des proies et la variation des types de proies du pangolin selon le sexe et l'âge de l'individu, mais également se concentrer sur l'évaluation de la composition biochimique et de la valeur nutritionnelle des insectes proies du pangolin afin d'offrir des substituts alimentaires pour l'élevage et la réintroduction.

Mots clés : Pholidota, pangolin, ecotone forêt-savanne, comportement nutritionnel, régime alimentaire, préférence d'habitat et de proies, connaissance de l'écologie endogène, Cameroun

Introduction

There are 216 mammals known to consume insects, amongst which some are obligate insectivores (Redford, 1983). Pangolins are entirely insectivorous mammals. They comprise a group of eight extant species mostly distributed in tropical and subtropical Asia and sub-Saharan Africa (Heath, 2013). Pangolins are unique among mammals in that they have a dermal made of overlapping keratinized scales rather than hairs (Heath & Coulson, 1998). They are primarily myrmecophagous and most of the species are nocturnal to crepuscular. Pangolins are solitary except within mating periods and before offspring weaning (Gaubert, 2011; Pietersen *et al.*, 2014; Pietersen, 2013).

Located in Central Africa, Cameroon is home to three pangolin species—the giant pangolin, *Smutsia gigantea* (Illeger, 1815), white-bellied pangolin, *Phataginus tricuspis* (Rafinesque, 1821), and black-bellied pangolin, *Phataginus tetradactyla* (Linnaeus, 1766). Their range extends to the southern region of the country Kingdon & Hoffmann (2013). The giant pangolin, black-bellied and white-bellied pangolins mostly share their range, extending from West to East Africa (Heath, 2013; IUCN, 2019). The giant pangolin is a burrowing species while, black-bellied and white-bellied pangolins are arboreal and semi-arboreal respectively Kingdon & Hoffmann (2013). Their habitats are primarily moist tropical lowland forests, secondary growth, mosaics of forest-savanna habitats, and riparian and swampy areas (Kingdon & Hoffmann (2013); Pietersen *et al.*, 2019; Nixon *et al.*, 2019). Pangolins are specialized in eating ants and termites (Swart *et al.*, 1999; Gaubert, 2011; Lee *et al.*, 2017; Pietersen *et al.*, 2016). They consume large amounts of ants and termites, with more than 70 million prey individuals eaten by one pangolin annually and up to 200,000 ants eaten during a single meal (Shi & Wang, 1985 cited by Durojaye & Sodeinde, 2014). The strong specialization of pangolins on an insectivorous diet limits trophic competition with other groups of mammals (Gaubert, 2011). Pangolin defense mechanisms against predators include; rolling up into a ball (with only the scaled body surfaces presented to predators and/or lashing out with a strong tail) which makes them highly susceptible to overexploitation (Kingdon, 1971).

Populations of Asian pangolins have severely declined due to local demand for pangolin meat in their range states and increasing international demand for pangolin scales (Loucks *et al.*, 2009). Large-scale international trafficking of African pangolin scales has emerged in the last decade (Heinrich *et al.*, 2017; Ingram *et al.*, 2019a), amplified, in part, by the growing economic ties between the African and Asian continents (Mambeya *et al.*, 2018). Pangolins in Africa are threatened by intense and widespread hunting for bushmeat and supplying the international trade of scales mostly for Traditional Chinese Medicine (TCM). Pangolins are easily hunted as they are slow-moving and have poor eyesight, making them vulnerable to hunters by manual catches and snares (Burton, 2009); habitat loss and fragmentation are additional threats (Challender, 2011; Challender & Hywood, 2012). All pangolin species found in Cameroon are rapidly declining due to over-exploitation (Bräutigan *et al.*, 1994, Kingdon & Hoffman, 2013). To prevent their extinction, all African pangolin species were upgraded to CITES Appendix I in 2017 (CITES, 2017) and they are listed as Endangered (GP and WBP) or Vulnerable (BBP) on the IUCN Red List of Threatened species (Nixon *et al*., 2019; Pietersen *et al*., 2019; Ingram *et al*., 2019b). Therefore, there is an urgent need to plan conservation actions for these species. For example, a better understanding of pangolin feeding ecology can inform the husbandry of seized and rescued animals intended for release back to the wild (Karawita *et al*., 2020); however, these data are still lacking.

Most of the published literature on pangolins covers the ecology, biology, and trade of Asian pangolin species. The diet of Asian pangolins has been well-studied by Li *et al.* (2011), Mahmood *et al.* (2013), Mohapatra *et al.* (2013), Ashokkumar *et al.* (2017), and Lee *et al*. (2017). Prey abundance and diversity surveys for some African pangolin species have also been carried out, such as the prey community assemblages and availability as food for pangolins (Swart *et al*., 1999; Li *et al.*, 2011; Pietersen *et al.*, 2016). The diet of Temminck's ground pangolin, *Smutsia temminckii* (Smuts, 1832) is the best-studied model of African pangolin species (Coulson, 1989; Swart *et al.*, 1999; Kingdon & Hoffman, 2013; Pietersen *et al*., 2016). Data on pangolin diets are typically derived from scat (Mahamood *et al*., 2013) and stomach content analyses (Gao, 1934; Minami, 1941; Coulson, 1989; Lee *et al*., 2017; Ashokkumar *et al*., 2017). They are known to feed in insect microhabitats with concentrations of termites and ants (e.g., termite mound, death wood), through continuous in and out tongue movements while the insects swarm over the animal (Kingdon, 1971). Though direct observation of radio-tagged pangolin feeding activities data is available for Temminck's ground pangolin (Pietersen *et al*., 2016), knowledge of diet and feeding behavior is still limited for the other African pangolin species.

Data on pangolin life history and ecology are challenging to obtain due to their low population density and their limited detectability through common monitoring approaches effective for other mammals (Nash *et al.*, 2016; Shek *et al.*, 2007). Camera traps have become an important tool for monitoring rare and cryptic species (Cutler & Swann, 1999; Shek *et al.*, 2007; Willcox *et al*., 2019). Camera-traps are also recommended as a useful method to assess species behaviors (Ahumada *et al*., 2019; Willcox *et al*., 2019), including foraging habits (Bridges & Noss, 2011; Karawita *et al*., 2020). They offer a reliable and non-invasive method for detecting species presence and their activity in the wild (Araujo & Chiarellio, 2005; Giman *et al*., 2007; Tobler *et al*., 2008), increasingly applied to study pangolins (Ichu *et al*., 2017; Bruce *et al*., 2018a). Local Ecological Knowledge-based survey is an alternative and rapid method to detect a species in its range. Local

Ecological knowledge is an important tool to inform conservation management decisions and has been increasingly applied elsewhere in Asia and part of West African countries to record the past and present status of pangolins, and threats to their population based on the perception of local communities (Golden *et al.*, 2013; Durojaye & Sodeinde, 2014; Nash *et al.*, 2016). Interview-based surveys have been conducted in West Africa where pangolins are reportedly used for traditional medicine (Boakye *et al.*, 2014; Soewu & Adoyele, 2009; Soewu *et al.*, 2020) but data from local ecological knowledge are lacking in Central Africa.

Cameroon has been identified as a major actor in the trafficking of pangolin scales (Ingram *et al.*, 2019a). Since the transfer of pangolins from CITES Appendix II to CITES Appendix I (CITES, 2017), pangolins have now been classified as a Class A species in Cameroon, affording them the highest level of protection (MINFOF, 2017). Poaching and trafficking of pangolins in Cameroon remain rampant despite the protection afforded to them under Cameroonian law (Ingram *et al*., 2019a). The three pangolin species that occur in Cameroon are threatened due to illegal hunting for commercial bushmeat trade and international trafficking of pangolin scales for Traditional Medicine (TM) in Asia, especially in China and Vietnam (Gomez & Sy, 2018). Given the trafficking pressure that pangolin populations are facing in Cameroon, there is an urgent need to develop conservation strategies for these species. This passes through the understanding of the life history of pangolins. For example, feeding ecology and habitat use for West and Central African pangolin species remain poorly known and create challenges for managing wild populations or animals rescued from the illegal wildlife trade. Reintroduction to the wild of confiscated live pangolins from trade is being explored as a conservation action. However, the husbandry of seized animals is challenging as the diet of pangolins is poorly known and little studied. Knowledge of how and where pangolins forage and which species they consume represents essential information for successful conservation programs in the wild and for *ex-situ* populations in zoos and sanctuaries. A better understanding of pangolin diets is needed to inform the husbandry of seized and rescued animals intended for release back to the wild (Kariwata *et al.*, 2020). However, the natural history of these three species, their diets, habitat preferences, and seasonal changes in behavior are still poorly known, and these gaps impede the ability to develop effective conservation strategies for these threatened species. For example, it would be useful to know what kinds and composition of habitats are required to support viable populations of different species within protected areas and other pangolin sanctuaries. The present thesis investigates the feeding behavior, food preferences, and habitat preferences of Cameroon's giant pangolin, black-bellied pangolin, and white-bellied pangolin in two national parks that occur in the northern forest-savanna transition zone.

Research questions

Principal question: Which habitat conditions could be favorable for the conservation of African pangolins in the two studied protected areas?

Secondary questions:

1) Do the local communities have a good ecological knowledge of pangolins? Does their knowledge reasonably correspond with what is observed in habitat and food preferences from ecological studies?
2) Do giant pangolin, black-bellied pangolin, and white-bellied pangolin have similar feeding behavior in the different types of habitats and seasons in Deng Deng and Mpem et Djim national parks?
3) Are potential ant and termite preys of pangolins present in both parks and what are their community compositions in the different habitat types by seasons?
4) Do giant pangolin, black-bellied pangolin, and white-bellied pangolin display different diet compositions and prey preferences?

Research hypothesis

Principal hypothesis: Some habitat types in Deng Deng National Park and Mpem et Djim National Park are more favorable for occupancy and use by giant pangolin, black-bellied pangolin, and white-bellied pangolin.

Secondary hypothesis:

1) The local communities have a good ecological knowledge of pangolins and their knowledge reasonably corresponds with what is observed from ecological field studies.
2) Pangolin species in the two localities studied have similar feeding behavior, habitat preferences, and seasonal changes in habitat use.
3) Potential ant and termite preys of pangolins are present in Deng Deng National Park and Mpem et Djim National Park and their occurrence and diversity change in different habitat types and seasons.
4) The three species of pangolins in Cameroon have different diet compositions and prey selectively on different sets of ants and termites. There are seasonal differences in the prey selectivity of different pangolin species.

Objectives

General objective

The present study aimed to contribute to pangolin conservation in Cameroon through investigation of their feeding ecology in a savanna-forest transitional zone of Deng Deng and Mpem et Djim national parks.

Specific objectives

The specific objectives of this study were to:

1) Compare local ecological knowledge on pangolins in local communities with ecological data gathered;
2) characterize the behavior of pangolins in the vegetation formations of both national parks using camera traps;
3) evaluate the presence and seasonal variability of the potential prey species of pangolins in the different vegetation formations;
4) investigate diet composition, the selectivity and seasonal changes in habitat use and prey species eaten by pangolins.

Importance of this study

The importance of this thesis is to improve knowledge on the feeding habits and diet composition of pangolins in Central African forests. Such information can help conservationists and wildlife managers to better conserve the species, particularly when assessing the importance of protecting different habitat types and their associated prey and the challenges of maintaining captive animals. For this reason, we collected information on the foraging habits and diet composition of pangolins in Cameroon. These information's could contribute to the implementation of reintroduction programs and the possibility of establishing pangolin sanctuaries. This thesis can improve our understanding of pangolin ecological traits, which can help in the long term to design and manage viable pangolin sanctuaries (1) by ensuring that an adequate mix of different habitats is included within sanctuaries (2) and that sufficient areas of key habitats are incorporated to be able to sustain viable populations of each species.

Organization of the thesis

This work prior presents an introduction that gives the context of pangolin distribution, scales trafficking, conservation status, and states the key questions to be answered. In the first chapter, a literature review gives all information on the past and present knowledge on pangolin classification, biology, ecology, threats, conservation efforts, challenges and limits to conservation practices, and finally a review of the different methods used to survey pangolins. The second chapter details the material and methods used to achieve this study's objectives. It is followed by a third chapter which presents results and discussion. This thesis' last section is the conclusion of relevant findings, future research perspectives and recommendations for future conservation initiatives.

Chapter I:

Literature review

I.1 History of pangolin classification

From modern classification, pangolins belong to the phylum of Vertebrate, the class of Mammalian; order of Pholidota Weber, 1904 and the family Manidae Gray, 1821 (Mckenna & Bell, 1997). The word Pholidota is derived from the Greek *pholis* or *pholidos* which means horny scale. Manidae is derived from the Latin word *manes*, meaning the spirit of the dead (also called ghost) and referring to the quiet and nocturnal habits of most pangolin species (Gotch, 1979). The order Pholidota is considered to have diverged from other Eutherian mammals around the early Cretaceous (Springer *et al.*, 2005; Rose *et al.*, 2005). Pangolins were previously included in the Order Xenartha along with armadillos, sloths, and South American anteaters likely due to similarities in protective scales and adaptations for feeding on ants and termites (Griffiths, 1968; Rose *et al.*, 2005).

I.1.1 Extinction in Pholidota group

The Pholidota had representatives in Europe, North America, and Southern Asia (now extinct). Nine fossil species of pangolins are known (Kingdon & Hoffmann (2013). including:

- three species discovered in the middle Eocene Europe, namely *Eomanis waldi* Storch, 1978 (Storch, 1978; Koenigswald *et al.*, 1981), *Euromanis krebsi* Storch & Martin, 1994 (Storch & Martin, 1994; Horovitz *et al.*, 2005), and *Eurotamandua joresi* Storch, 1981;
- one unnamed species (Gebo & Rasmussen, 1985) recorded from the early Oligocene of Egypt;
- one species which occurred in the latest Eocene from North America, named *Patriomanis americana* Emry 1970 (Emry, 1970; Patterson, 1978), which closely resembles *Necromanis* Filhol, 1893 from the Oligocene-Miocene of Europe (Koenigswald & Martin, 1990; Koenigswald, 1999);
- three species recorded in the recent Plio-Pleistocene, respectively, from Europe, Africa, and Southern Asia, and related to the genus *Manis*: *Manis palaeojavanica* Dubois, 1907 (Dubois, 1972) from Java the largest *Manis* species; *Manis lydekkeri* Dubois, 1908 from India (Dubois, 1977) and *Manis hungarica* Kormos, 1934 from Hungary (Kormos, 1934 cited by Kingdon & Hoffmann, 2013).

I.1.2 Current Manidae classification

Previously, pangolin classification had recognized a single genus, *Manis*, but recent morphological (Patterson, 1978; Mckenna & Bell, 1997; Gaudin & Wible, 1999; Schlitter, 2005) and phylogenetic analyses (Gaudin *et al.*, 2009) recommended the subdivision into three different genera including *Manis* Linnaeus, 1758 specific to Eastern Asia, *Smutsia* Gray, 1865 and *Phataginus* Rafinesque, 1821 that occur only in sub-Saharan Africa.

- **The genus *Smutsia* (two species):**

Smutsia temminckii (Smuts, 1832)

This African species is commonly called Temminck's pangolin or Cape/Steppe pangolin. It was previously included in the genus *Manis* with *Smutsia* usually considered a subgenus. It was referred to *Phataginus* by Grubb *et al.* (1998), but today it is included in the genus *Smutsia*, along with another African species, the giant pangolin *Smutsia gigantea* following Gaudin *et al.* (2009).

Smutsia gigantea (Illiger, 1815)

This species is also called giant ground pangolin but more commonly giant pangolin with the synonym scientific name *Manis gigantea* Illiger 1815. It has been included in the genus *Manis* by several authors with *Smutsia* sometimes considered as a subgenus. It was also referred to the genus *Phataginus* with the two other small African pangolins by Grubb *et al.* (1998), but it is currently included in the genus *Smutsia* following Gaudin *et al.* (2009).

- **The genus *Phataginus* (two species):**

Phataginus tetradactyla (Linnaeus, 1766)

This African native species is commonly called Black-bellied or Long-tailed Pangolin with the synonym scientific names *Manis tetradactyla* (Linnaeus, 1766) or *Uromanis tetradactyla* (Linnaeus, 1766). It was long included in the genus *Manis* by some authors with *Uromanis* usually considered a subgenus. This species was referred to *Uromanis* by McKenna & Bell (1997) but it was definitively assigned to the genus *Phataginus* following Gaudin *et al.* (2009).

Phataginus tricuspis (Rafinesque, 1821)

This species is commonly called African white-bellied/ Three-cusped/ Tree Pangolin. The synonym scientific name of this species is *Manis tricuspis* Rafinesque 1821. Once included in the genus *Manis* with *Phataginus* sometimes considered a subgenus, it is now classified in the genus *Phataginus* following Gaudin *et al.* (2009). Meester & Setzer (1972) recognized two distinct subspecies, *Manis tricuspis tricuspis* and *Manis tricuspis mabirae* (occurring specifically in Uganda), with the latter considered distinct, while Kingdon & Hoffman (2013) considered that there were no subspecies for white-bellied pangolin.

- **The genus *Manis* only in Asia (four species):**

Manis culionensis (de Elera, 1915)

This Asian species is commonly called the Philippine pangolin. It has traditionally been considered a subspecies of the Malayan Pangolin *Manis javanica* then was described and recognized as a distinct species from *M. javanica* by Feiler (1998). This was supported by a redescription study of discrete morphological characters (Esselstyn *et al.*, 2004; Gaubert & Antunes, 2005; Schlitter, 2005).

***Manis javanica* Desmarest, 1822**

This Asian pangolin is commonly called Sunda or Malayan pangolin. Populations of pangolins occurring in the Philippines were formerly attributed by mistake to this species *Manis javanica.* In the recent classifications, Feiler (1998) and subsequently Gaubert & Antunes (2005) have separated and distinguished two species under the names *Manis culionensis* and *Manis javanica*.

***Manis pentadactyla* Linnaeus, 1758**

This species is commonly called the Chinese or Formosan pangolin. The literature does not mention a taxonomic review of this species.

***Manis crassicaudata* É. Geoffroy, 1803**

This species is commonly called India or Thick-tailed Pangolin. Recent DNA analysis of seized pangolin scales in Asia suggests that another undescribed species of Asian pangolin may exist (D. Olson, pers. comm.).

I.2 Pangolin morphological characteristics

I.2.1 External morphology

Pangolins are medium- to large-sized mammals with an adult body mass ranging from 1 kg in the small arboreal species to 33 kg in the largest species. They are easily recognized and identified from other mammals with their protective keratinized scales covering the main body surface except for the ventral parts and legs cover by hair (Heath, 1992; Cota-Larson, 2017). The body length (that measured from the head to the abdomen) is ranged from 300 to 950 mm, and the tail length is between 350 to 880 mm according to species (Heath & Hammel, 1986). The females of pangolins are distinguishable from males by the presence of two small pectoral nipples at the axillary region of the forelegs.

Head and sense organs

The head of the pangolin is generally short and conical, almost tapering at the snout and nearly truncated with scales that extend nearly to the ears (Pocock, 1924). Pangolin’s eyes are small, black, and protected by thick eyelids. The ear openings are present, but the ear pinnae are small or absent (Doran & Allbrook, 1973; Fig.1). Figure 1 shows the morphological criteria to distinguish the juvenile and adult white-bellied pangolin.

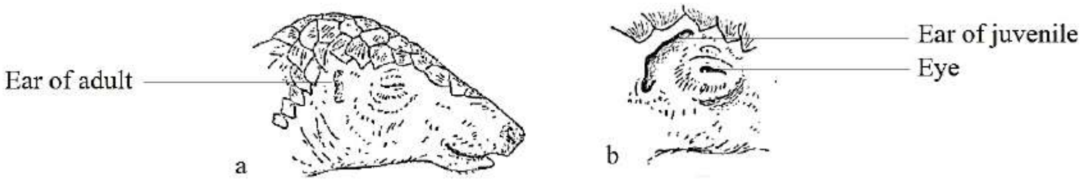


Figure 1: Head external characteristics of adult and juvenile *Phataginus tricuspis* a) Part of the head showing ear of adult *P. tricuspis*; b) Head of juvenile
Source: Pocock (1924).

Tail and scales variation

Pangolin scales are made up of keratinized epidermis on a flattened and caudally directed corium papilla (Werber, 1892). Scales are formed from agglutinated hair made up mainly of alpha- and beta-keratin that provide them elasticity and plasticity (Tong *et al*., 1995) allowing flexibility of the animal body. From Pocock's (1924) description, the tail is known to be well-developed and powerful, and approximately as wide at the base as the anal region in *Phataginus tricuspis* (Fig. 2a) and *Manis tetradactyla* (Fig. 2b). Some species are characterized by the presence of a naked cutaneous pad beneath the tip of the tail visible in *P. tricuspis* and *Manis tetradactyla* (Fig. 3A). There is a median area of naked skin due to the absence of two medians and two lateral scales in Asia pangolin. There are individual and species variations of scale colors from dark brown to yellow-brown (Fig. 3B) and shapes according to their position on the fore or hind limbs and heads and tails. Figures 2 and 3 show the differences between African and Asian species according to the number and shape of the scales at the tail's tip.

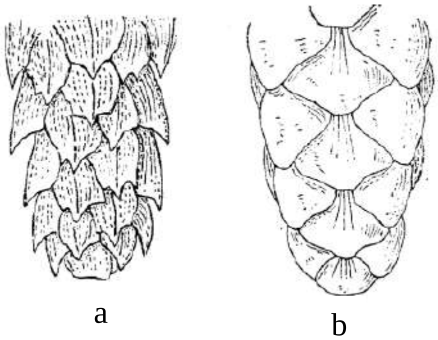


Figure 2: Tail scales characteristics showing morphological differences between two African pangolin species *P. tricuspis* and *P. tetradactyla* a) Upper side of *P. tricuspis* tail end showing the irregular arrangement of the scales; b) Upper side of *P. tetradactyla* tail end showing the regular arrangement of the scales and bristles
Source: Pocock (1924).

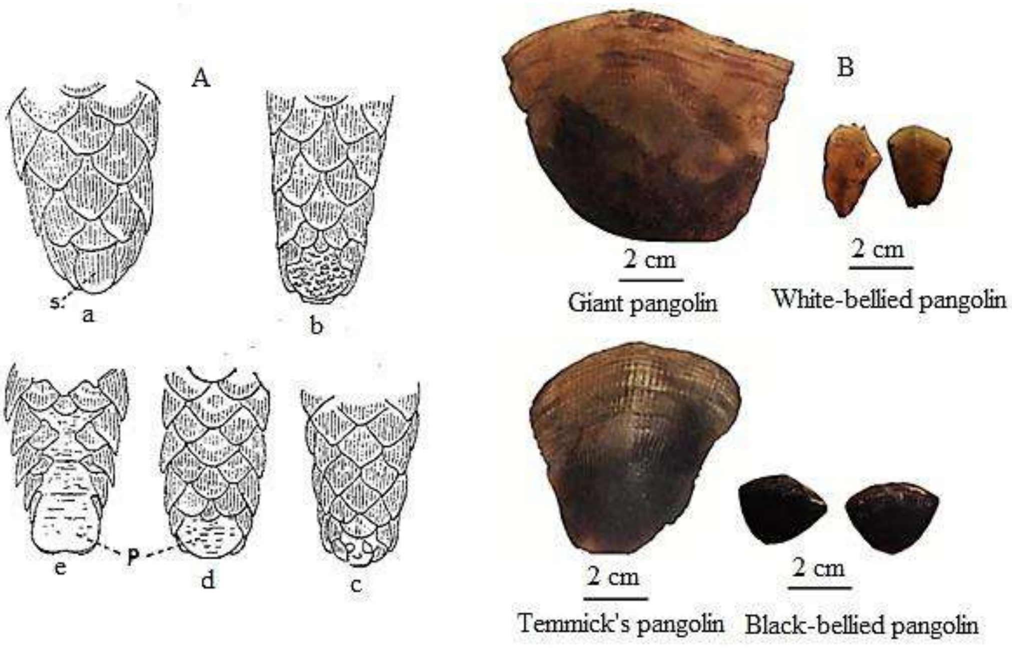


Figure 3: Scales shapes and characteristic on tail (A) Criteria of recognition of the lower side of *P. tricuspis* adult end of the tail showing the naked terminal pad (P) and the naked skin above it different from the terminal scale (S) of *M. crassicaudata* (a); *Phataginus pentadactyla* (b); the young specimen of *M. pentadactyla* (c) and the naked terminal pad of *M. javanica* (d); (B) scales of African pangolin species Sources: A: Pocock (1924) and B: Cota-Larson (2017).

Limbs of pangolins

According to species, the fore and hindfeet of pangolin end with four or five clawed digits (Kingdon, 1971; see Figs. 4, 5). The hindlimbs are powerful. Forelimbs have long robust claws reminiscent of the American anteater *Patriomanis americanus* (Emry, 1970). The forefoot has five digits of which the 3rd is always the largest, the 2nd and the 4th larger than the 1st. The 2nd, 3rd, 4th and 5th digits carry the falcate fossorial claws. The relative length and disposition of the digits of the hind foot of *M. pentadactyla* and *M. javanica* are nearly the same as in the forefoot in the sense that the 2nd, 3rd, and 4th digits are the largest and the 1st and 5th the smallest of the five (Pocock, 1924).

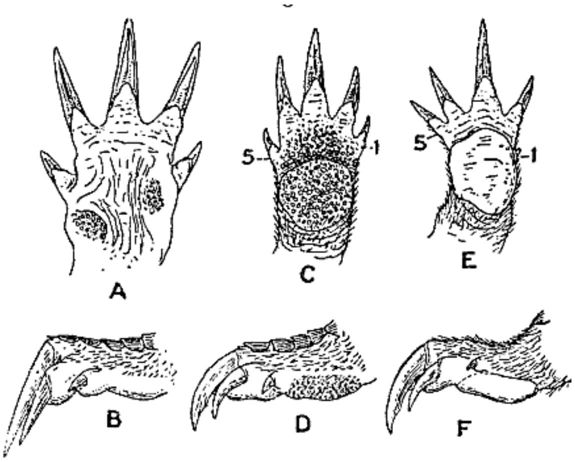


Figure 4: Different characteristics of pangolin forefoots: A) the right forefoot of young M. pentadactyla from below; B) the same from the inner side; C) the right forefoot of M. javanica from below; D) the same from

the inner side; E) right forefoot of M. tricuspis from below; F) the same from the inner side; 1=first digit and 5= fight digit.
Source: Pocock (1924).

Figure 5 shows the different characteristics of giant pangolins' hind feet compared to Asia pangolins similar to white-bellied and black-bellied pangolins

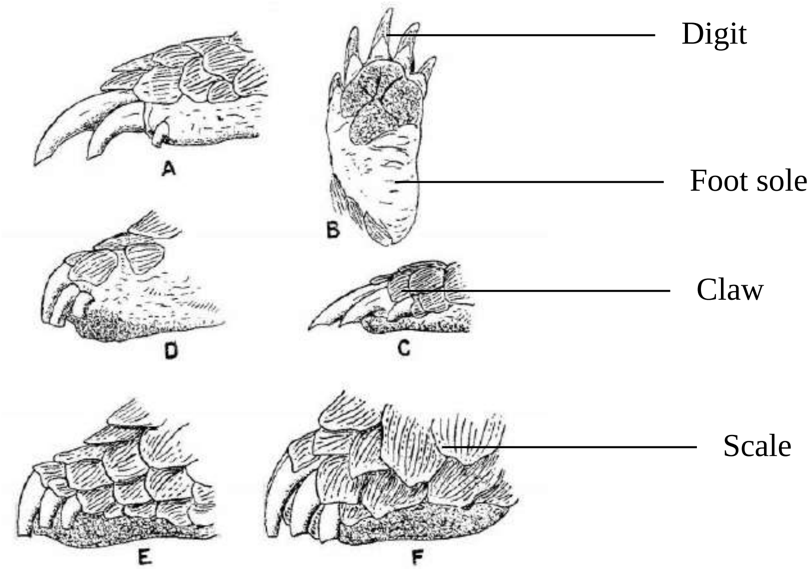


Figure 5: Different characteristics of giant pangolins' hind feet compared to Asia pangolins similar to white-bellied and black-bellied pangolins: A) Right hind foot of *M. javanica* adult from the inner side; B) Right hind foot of adult *M. pentadactyla* from below showing lobate pad; C) the same of the outer side; D) Right hind foot of *M. crassicaudata* from inner side; E) Left hind foot of the same from outer side; F) Left hind foot of adult *S. gigantea* from the outer side
Source: Pocock (1924).

I.2.2 Internal features

Mouth

The digestion system of the pangolin is poorly studied. The mouth opening of the pangolin is small. Pangolins have no teeth, just a narrow-raised ridge of bone on the upper jaw in the tooth rows position. They are characterized by their long slender tongue coated with sticky saliva which is used for lapping up ant and termite prey. Tongue total length range from 30 cm for the small pangolin to 40-70 cm for the Temminck's and giant pangolin, respectively (Doran & Allbrook, 1973). It extends nearly half its resting length outside the mouth (Heath, 2013). The anterior portion of the tongue is covered with a high density of fascicles, suggesting a sensory (i.e., prey location) rather than a gustatory function. The tongue also lacks papillae indicating that it accomplishes mostly a transport function rather than taste (Ofusori *et al.*, 2008). Pangolins are warm-blooded mammals with body temperatures ranging from 26 to 35° C.

Stomach

Published studies on pangolin morphological anatomy are very scarce. Information regarding pangolin digestive systems remain sparse and are from some species models. The stomachs of the pangolin display different anatomical and structural variations according to the species (Fig. 6). For example, there is one chamber in the Sunda pangolin and two chambers in the Chinese pangolin where the unchewed food is macerated (Fang, 1981). When two chambers are present the first one is a larger chamber (4/5th of the total size) having a thin wall and with a food storage function. The second chamber has thick muscular walls and a special rough, hard semi-spherical tissue near the pylorus (Fang, 1981) which is covered in cornified denticules. The stomach content is very large. For example, the Chinese pangolin stomach content was estimated to be 0.5 kg of termites (Fang, 1981). The gizzard-like stomach is lined by stratified squamous epithelium well keratinized with dense collagen fibers that offer protection against ulceration by the hard chitinous parts of ants and termites (Ofusori *et al*., 2008). Figure 6 shows internal digestif morphological features of different pangolin species and a stomch of a Chinese pangolin.

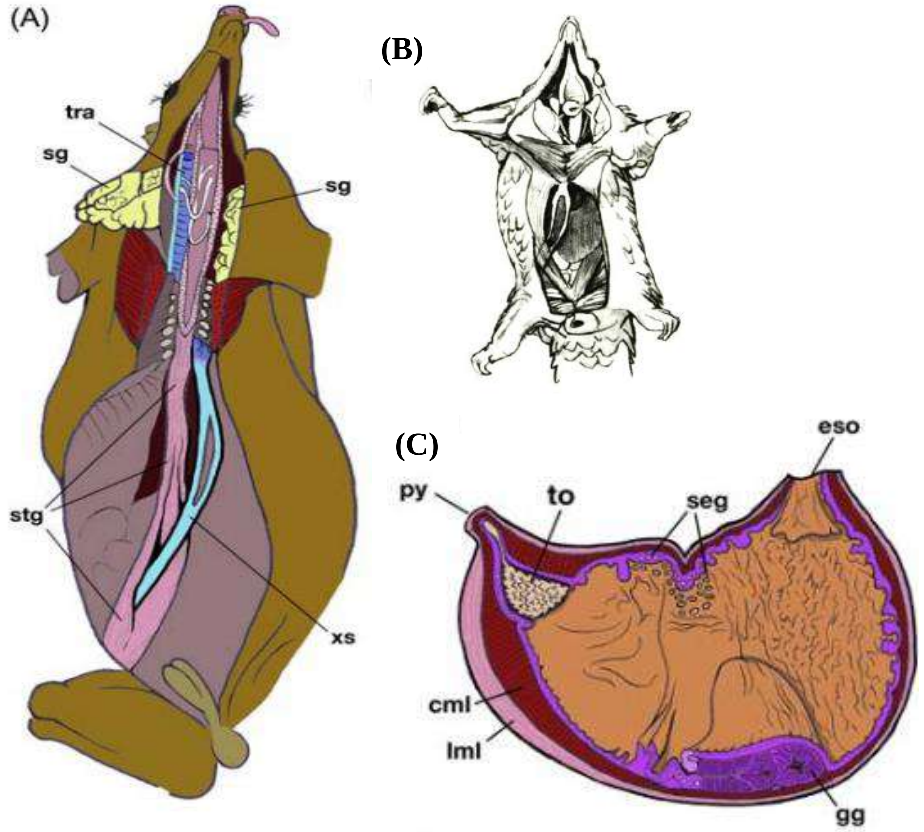


Figure 6: Internal digestif morphological features of different pangolin species (A) Dissected *Smutsia gigantea* in ventral view, showing salivary glands, xiphisternum, and elongated tongue musculature from Kingdon (1971) modified. (B) Dissected *Phataginus tricuspis* in ventral view; (C) *Manis javanica* stomach photo from Ashokkumar *et al*. (2017). Abbreviations: cml, circular layer of smooth muscle fibers; eso, esophagus; gg, gastric glands; lml, a longitudinal layer of smooth muscle fibers; py, pylorus; seg, serous glands; sg, salivary glands; ss, Sylvian sulcus; stg, sternoglossus muscle; to, triturating organ, lined with cornified denticles; tra, trachea; xs, xiphisternum.

I.3 Pangolin bio-ecology

I.3.1 Pangolin ecology

I.3.1.1 Pangolin distribution

I.3.1.1.1 Distribution of pangolins in Sub-saharan African

Previously covering Europe, North America, and Southern Asia, pangolins are now restricted to Asia and Africa. Pangolins were primarily distributed in Southeastern and Southern Asia, as well as most of sub-Saharan Africa (Kingdon & Hoffman, 2013). The availability of certain insect preys, ambient temperatures, and availability of water determine the distribution of pangolins (Swart *et al*., 1999; Challender *et al*., 2020).

I.3.1.1.1.1 *Phataginus tetradactyla*

The black-bellied pangolin is endemic to Africa. This species is reported in West and Central Africa (see Fig. 7). Senegal is listed as the western limit of its distribution (Grubb *et al.*, 1998; Meester, 1972) which extends to the west of Sierra Leone where it is reported to be scarce. From Sierra Leone, the species range extends through the Central African lowland forests with a gap between Central African and West African populations that also occur in Liberia, Côte d'Ivoire, and South West Ghana (Barnett & Prangley, 1997; Fig. 7). It occurs in southern Cameroon throughout much of the Central African forest block west to the Semliki Valley, but the presence in Uganda is not yet confirmed (Malbrant & MacLatchy, 1949; Rahm, 1966).

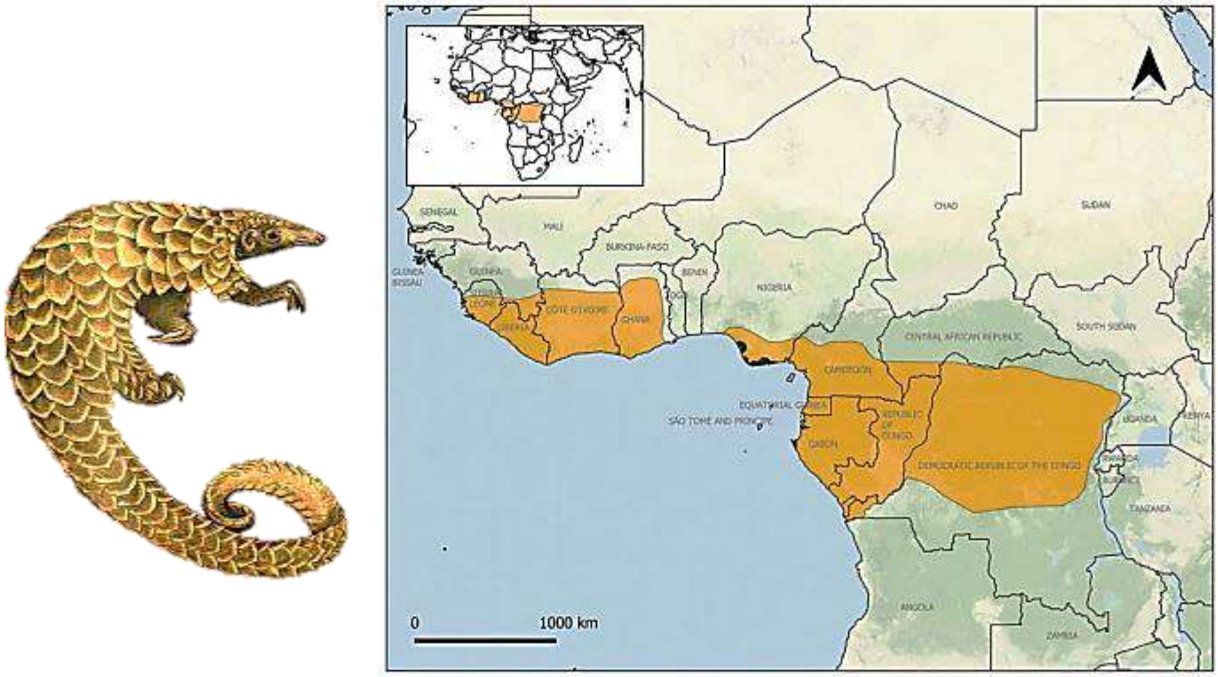


Figure 7: Morphological features and the home range of black-bellied pangolin
Photo credit: Pangolin, Kingdon & Hoffmann (2013); map source: Ingram *et al.*, 2019.

I.3.1.1.1.2 *Phataginus tricuspis*

The white-bellied pangolin distribution extends from Guinea in West Africa to Central Africa through Sierra Leone, southwest Kenya, northwest of Tanzania, to the northwest of Zambia and Angola (Hill & Carter, 1941, Schouteden, 1948, Rahm, 1966, Kingdon, 1971, Ansell, 1978, Grubb *et al.*, 1998; Fig.8). The western distribution limit of this species is Senegal, although there are no records in Gambia and Guinea-Bissau (Grubb *et al.*, 1998, Kingdon & Hoffmann, 2013).

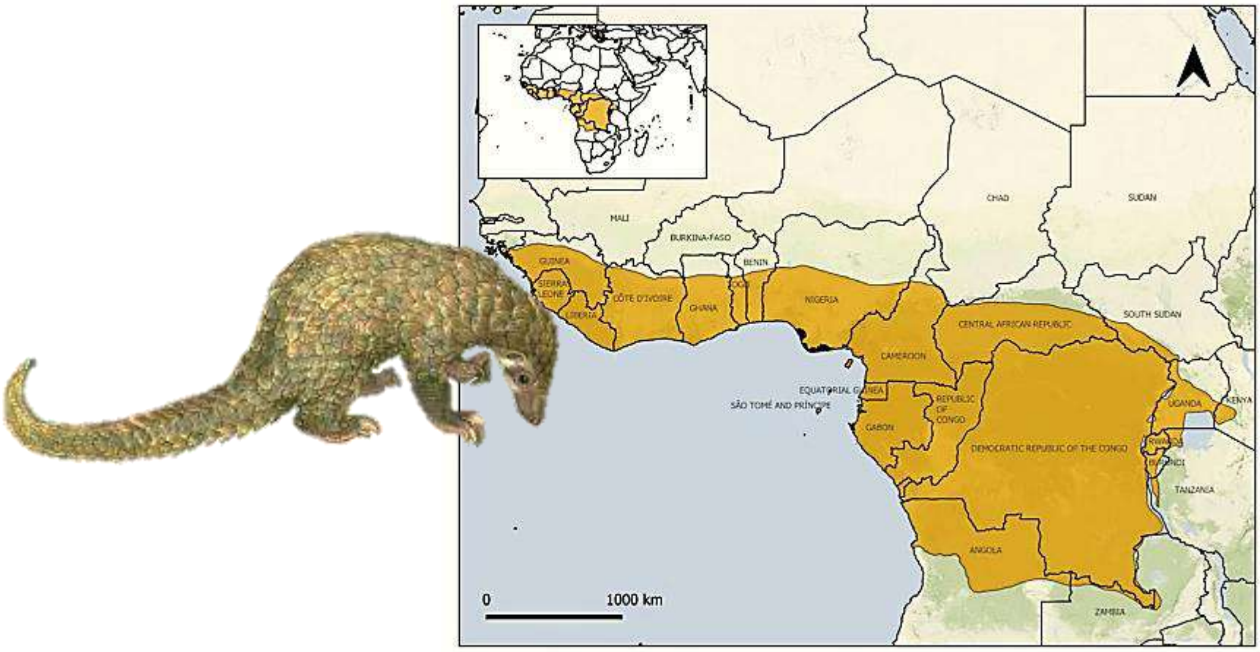


Figure 8: Morphological features and the home range of white-bellied pangolin
Photo credit: Pangolin, Kingdon & Hoffmann (2013); map source: Pietersen *et al.*, 2019.

I.3.1.1.1.3 *Smutsia gigantea*

The giant ground pangolin inhabits forests and forest-savanna mosaics in the sub-Saharan Africa region (Fig 9). Its range extends from Senegal (Dupuy, 1968) through Guinea, Sierra Leone, Côte d'Ivoire (Rahm, 1956), Ghana, Togo (Grubb *et al.*, 1998; Kingdon & Hoffmann, 2013), Benin (Sayer & Green, 1984) and Liberia with no documentation in Gambia and Nigeria. The giant pangolin is also found in Cameroon through to Uganda and South Sudan (Hatt, 1934; Schouteden, 1948; Malbrant & MacLatchy, 1949; Rham, 1966; Pagès, 1970; Kingdon, 1971; Kingdon & Hoffmann, 2013) and in the lakeshore in West Kenya close to the Uganda boundary and in West Tanzania (Kingdon, 1971).

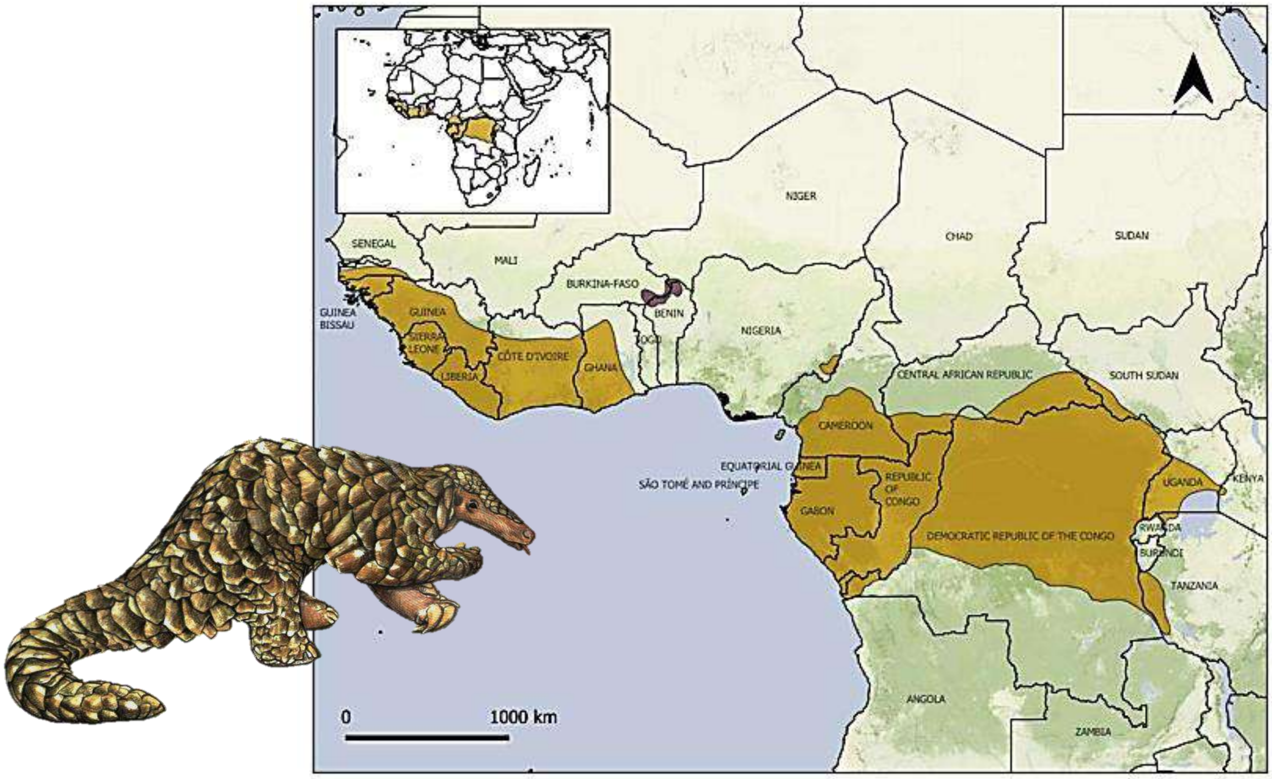


Figure 9: Morphological aspect and the home range of giant ground pangolin. Purple shading indicates areas where the species is possibly extinct.
Photo credit: Pangolin Kingdon & Hoffmann (2013); map source: Nixon *et al*., 2019.

I.3.1.1.2 Distribution of pangolins in Cameroon

Giant ground pangolin is found in the Adamoua Region at Mbam & Djerem National Park, and the eastern bank of the Sanaga River (Kingdon, 1971). No other published surveys are providing a clear and detailed distribution of pangolins in Cameroon. Only opportunistic records during wildlife inventory surveys provide basic knowledge of their presence in various localities across the country. For example, Bruce *et al*. (2018a, b) and Ichu *et al*. (2017) have recorded white-bellied and giant pangolins using camera traps. Ichu *et al*. (2017) mentioned the black-bellied pangolin species occurring in the Campo Ma'an National Park in the southwestern region. Other than regional distribution maps for the black-bellied pangolin (Ingram *et al*., 2019c), giant pangolin (Nixon *et al*., 2019), and white-bellied pangolin (Pietersen *et al*., 2019), no other published research is available that details the distribution of these species in Cameroon.

I.3.1.1.3 Central and West African pangolin habitats

I.3.1.1.3.1 *Phataginus tetradactyla*

This species mostly occurs in riverine and swamp forest habitats near permanent water courses, where vegetation is dominated by palm trees and specialized swamp trees of the genera *Uapaca*, *Pseudospondis,* and *Mitragina* (Gaubert, 2011; Kingdon & Hoffmann, 2013; IUCN, 2019). The black-bellied pangolins have also been recorded in the intact and disturbed primary and secondary rainforests, as well as in farmlands in Southeast Nigeria (Angelici *et al*., 1999). They spend nights in tree hollows or hollows in insect nests where they feed on ants and termites (Kingdon & Hoffmann, 2013).

I.3.1.1.3.2 *Phataginus tricuspis*

White-bellied pangolin occurs principally in moist tropical lowland forests, secondary growth, and in dense woodlands, particularly along water courses (Kingdon, 1971; Pagès, 1975; Gaubert, 2011; IUCN, 2019), and in altered forests, plantations, and farmlands in Nigeria (Angelici *et al.,* 1999). For example, it is often caught on abandoned oil palm trees (Sodeinde & Adedipe, 1994).

I.3.1.1.3.3 *Smutsia gigantea*

The giant pangolin occurs in lowland tropical moist and swamp forests, and in forest-savanna cultivation mosaic habitats where soils are suitable to dig (Kingdon, 1971). This species digs a long and complex burrow up to 40 m and up to 5 m below the surface, but may also use burrows dug by Aardvark (*Orycteropus afer*) Kingdon & Hoffmann (2013).

I.3.1.2 Pangolin diet composition

I.3.1.2.1 Generalities on ants and termites

Ants

Ants belong to the family Formicidae within the Order Hymenoptera. The taxon has evolved great ecological plasticity allowing ants to inhabit most ecosystems, including savanna, desert, forest, and urban areas (Majer, 1985; Majer *et al*., 1994; Morrison, 1996). Their ecological success proceeds mainly from their social organization. They have evolved to become the most species-rich and ecologically diverse group of social insects (Hölldobler & Wilson, 1990). Currently, there are about 12,500 described species of extant ants (Bolton *et al*., 2006), comprising 290 extant ant genera (Ward, 2010).

Ecological and functional roles of ants

Ants are a very important social insect group in almost all terrestrial ecosystems as they disperse seeds, assist soil processing and nutrient cycling, and are mutualists with a range of species (Huxley, 1980; Hölldobler & Wilson, 1990). Ants have various dietary adaptations. They can be omnivorous, opportunistic feeders, or herbivores, but many are specialist or generalist predators of invertebrates (Hölldobler & Wilson, 1990). These social insect groups play substantial ecological roles. For example, ants and termites make up the bulk of animal biomass in many tropical forests. Some that eat termites regulate the populations of termites and other keystone species. Some ant species are specialized termite feeders (Maschwitz & Schönegge, 1983; Mill, 1984) and some display mutualistic interactions between ants and termites, such as nest-sharing (Jaffe *et al.*, 1995; Diehl *et al.*, 2005).

Termites

Termites form part of the Order Blattodea along with cockroaches and mantids, a former member of the Order Dyctioptera. They are phylogenetically nested within the cockroaches (Inward *et al.*, 2007; Legendre *et al.*, 2008). Termites are distributed in a great variety of microhabitats in ecosystems, such as in the soil, on decomposing trunks, on leaf litter, in abandoned or active nests, and inside living trees or in their canopy. There are approximately 2,600 described species of termites (Kambhampati & Eggleton, 2000). The most recent classification splits those termites into eleven families, nine extant and two fossils. The Termitidae make up the bulk of extant species and are dominant in tropical regions, particularly rainforests, and savannas. Termopsidae and Kalotermitidae are the more recently evolved groups. The Hodotermitidae family is a specialized group close to the termopsids. The Rhinotermitidae are widespread, being the only family that extends significantly into subtropical and warm temperate regions (Weesner, 1965).

Ecological and functional roles of termites

Termites' abundance is mainly due to their specialist feeding behavior based on cellulosic and hemicellulosic substances widespread on the Earth (Duchesne & Larson, 1989; Watanabe & Tokuda, 2010). Termites feed upon various decaying plant matter (e.g., dead wood, leaf litter) and soil, and therefore, play major roles in decomposition and nutrient and carbon cycling processes (Eggleton *et al.*, 1997; Jones & Eggleton, 2000; Donovan *et al.*, 2001). Termites are the most important decomposer insects in tropical forests, tropical savanna, and desert ecosystems (Eggleton, 2011). The social systems of termites are unique, with important evolutionary contrast with analogous hymenopteran insects, such as ants (Eggleton, 2011). Termite morphological and anatomical adaptations are highly caste-specific. Castes evolve and develop structures independently. In reproductive castes, structures allowing their dispersal (alates), pair bonding, and fecundity are present. Worker castes have individuals for foraging and feeding immatures, nest construction, and soldiers develop structures for defense (Eggleton, 2011).

Ants and termites as food resources

According to Hölldobler & Wilson (1990), ants and termites represent almost 33% of the planet's terrestrial animal biomass and they provide ecological services to the ecosystem (Schyra *et al.* 2019). They are generally mentioned as a source of food for several vertebrate groups (Pietersen *et al.*, 2016; Li *et al.*, 2011; Swart *et al.*, 1999; Redford, 1987) or as food nutrient compensators (Deblauwe, 2009). Termites provide mammals with considerable quantity of nutrients, such as proteins, iron, and manganese. Ants also provide similar nutrients in low quantities (Redford, 1984). Several mammal groups feed predominately on ants rather than termites (Pietersen *et al.*, 2016; Swart *et al.*, 1999; Coulson, 1989).

I.3.1.2.2 Pangolin feeding ecology

I.3.1.2.2.1 Adaptation to insectivorous diet

Several morphological, anatomical, and physiological characteristics are associated with pangolins' specialized diet on termites and ants (Heath, 1992). Pangolin's olfactory sense is very acute. It is used to find and differentiate prey and non-prey species. Their forelegs have long and robust nails used to dig ant and termite nests (Doran & Allbrook, 1973). With their very long tongue, pangolins feed rapidly with continuous tongue movement while the insects swarm over the animal (Kingdon, 1972). During feeding, the tongue is repeatedly extended and retracted (Ofusori *et al.*, 2008). Rapid intrusion and retraction of the tongue coated with a salivary slime produced regularly enable pangolins to harvest large numbers of termites and ants. Preys are scraped from the tongue using the hyoid bone and directed down the esophagus to the stomach where it is masticated (Doran & Allbrook, 1973). The contractions of the muscular structure grind food before passing into the intestine (Fang, 1981).

I.3.1.2.2.2 Foraging ecology and diet composition

The black-bellied pangolin is reported to have a particularly specialized diet (Kingdon & Hoffmann., 2013). However, diet information for this species is scarce and their preys are poorly known. Kingdon & Hoffmann (2013) suggested that this species eats tree ants, including the genera *Crematogaster* and *Cataulacus*. The white-bellied pangolin diet is mainly ant and termite species. Army ants being an important food source, including species of the ant genera *Dorylus* and *Myrmicaria*, *Camponotus*, *Cataulacus*, *Oecophylla,* and *Crematogaster* spp. (Pagès, 1970), adults and nymphs of the termite genera *Nasutitermes* and *Microcerotermes* (Kingdon, 1971; Kingdon & Hoffmann, 2013). White-bellied pangolin feed by digging with the foreclaws into the colonies of termites and ants in trees, ground mounds, and fallen logs (Pagès, 1975). For the giant pangolin, the diet has been reported to be predominantly termites, including the genera *Macrotermes*, *Isognathotermes*, *Apicotermes*, *Protermes* and *Pseudacanthotermes.* Some ant genera, such as *Palthothyreus* spp. and *Anomma* spp. have also been documented as food items (Vincent, 1964; Pagès, 1970; Kingdon, 1971). Bequaert (1922) recorded the species feeding on eleven ant species. Water beetles (Dytiscidae) are reported to be eaten by the giant pangolin (Kingdon & Hoffmann, 2013).

I.3.1.3 Pangolin reproduction

I.3.1.3.1 Pangolin reproduction behavior

Pangolins are placental mammals that give birth to one offspring per year and rarely two (Pagès, 1975, Heath & Coulson, 1977). During mating periods, the female urine and glandular scent are followed by adult males. They come together only for a short time for mating. The degree to which different species of pangolin share burrows remains unclear, but it is known that pangolins are generally solitary. After birth, the offspring remain with the female and, occasionally, with the male for the next months (Pagès, 1975; Heath & Coulson, 1977). For Temmick pangolin young are weaned after one year but stay with the female until the next pregnancy (Kingdon & Hoffmann, 2013).

For *Phataginus tetradactyla,* the breeding seems to be continuous and is influenced by seasonal weather changes. A female can conceive within 9 to 16 days after the previous birth. The gestation period is approximately 140 days (Pagès, 1970; Pagès, 1975). The female has one offspring who is relatively well-developed. The young weighs 100-150 g and measures 30-35 cm in total length. The individual adult size is reached after 15 months. The young stays in a hole during the first week and, thereafter, climbs on the mother’s rump or tail where it begins to glean ants during the female feeding (Pagès, 1970; Pagès, 1975).

Phataginus tricuspis are solitary but the female and the juvenile can be found together (Pagès, 1965, Kingdon & Hoffmann, 2013). In Gabon the species breeding is continuous and the period of inactivity between pregnancies can be very short (Pagès, 1975). The gestation period is around 150 days and one offspring is typical (Pagès, 1965; Kingdon & Hoffmann, 2013). The home range had been estimated to be 20-30 ha in Gabon for the male and considerably smaller for the female (3-4 ha) (Kingdon & Hoffmann, 2013). A single male home range contains up to ten female home ranges, suggesting a polygynous behavior (Pagès, 1972).

For *Smutsia gigantea*, reproductive information is scarce; however, two birth events of a single giant pangolin young from Uganda in September and October are recorded by Kingdon (1971). The newborn pangolins’ length is up to 450 mm and weighs over 500 g. Breeding is continuous throughout the year but may have a peak in some regions. The period of gestation of this species and its longevity in the wild or captivity is poorly known. Hatt (1934) reported pregnancy in DR Congo during November and December.

I.4 Pangolin role

I.4.1 Ecological role

According to Chao *et al*. (2020), pangolins play several roles in ecosystems through predation on ants and termites, their burrowing lifestyle, participation in food networks as prey species for carnivores, and as hosts of parasites. The predating activity of pangolins controls ant and termite populations and likely influences their abundance and community structure, thus affecting local ecosystem function (e.g., trophic interaction, decomposition, nutrient cycling, and energy flows; see Del Toro *et al*., 2012). Pangolin influence soil processes through turnover of organic matter, aeration, and mineralization rates when digging burrows. They may also act as bioturbators, contributing to soil destratification and mixing and creating preferential flow paths for soil gas and infiltrating water (Challender *et al*., 2020).

I.4.2 Medicinal importance

Apart from Asia, pangolins are widely used in medicines in West Africa (Djagoun *et al.*, 2013) and part of Central Africa (Soewu *et al*., 2020). The white-bellied pangolin is widely used in traditional medicine practices to treat different diseases. According to Akpona *et al.* (2008), various organs including the skin, heart, intestine, and head are used for treating asthma, and cardiovascular and skin diseases. In Nigeria, *P. tricuspis* is reported to be used to treat medical conditions, including infertility, gastrointestinal disorders, rheumatism, venereal diseases, and back pains; local people also consider this animal to confer invisibility, as love potions, and for appeasing witches or evil spirits (Kingdon & Hoffmann, 2013). Juvenile pangolin and pregnant female individuals are specifically required in some traditional treatments (Soewu & Ayodele, 2009). Black-bellied pangolin utilization in medicine is not widely reported in the literature. Traditional Chinese Medicine (TCM) prescribes ground pangolin scale for a range of health benefits, including improved lactation, arthritis, skin, and virility, though there is no scientific evidence that ground scale has any efficacy for these uses. It is important to note that pangolin scales are just like human nails made of keratin and the therapeutic properties attributed to them have not yet been proven scientifically. Traditional Awori doctors in southwestern Nigeria reported pangolin products were used to treat 47 different ailments, 15 of which used scales (Soewu & Adekanola, 2011). In Nigeria, the scales have the greatest application in the southwest of the country and are used to treat mental illness, and kleptomania, to give luck, and drive away witchcraft, such as in Ghana and Sierra Leone. The scales can be used alone or with other ingredients. A survey in Sierra Leone identified 22 pangolin body parts, most commonly scales, prescribed for the treatment of 59 diseases (Boakye *et al.,* 2014). In Sierra Leone, Benin, Ghana, and Nigeria the body parts of the white-bellied pangolin, including the head, heart, blood, eyes, intestines, tongue, and scales are prescribed by traditional healers to treat a multitude of ailments (Soewu *et al*., 2020). In southwestern Cameroon, the scales of tree pangolins are used as blades and their skins are used to make drums (Bobo *et al*., 2015). Local people near Korup National Park, report that the scales of white-bellied and black-bellied pangolins are used to treat stomach disorders (Bobo & Ntum Wel, 2010). They are usually burned and/or ground into a powder and mixed with palm oil or water which is then ingested to purge the stomach.

I.4.2.1 Pangolin and Covid-19 pandemic

Pangolins are suspected to host (primary or secondary it is unclear) Coronaviruses similar to those of SARS-CoV-21 (Lahm *et al.*, 2020). This pandemic has been tentatively associated with a seafood market in Wuhan, China, where the sale of wild animals may be the source of zoonotic infection. Although bats are likely reservoir hosts for SARS-CoV-2, the identity of any intermediate host that might have facilitated transfer to humans is unknown. SARS-CoV-2-related coronaviruses were identified in Malayan pangolins (*Manis javanica*) seized in anti-smuggling operations in southern China (Lahm *et al.,* 2020). Metagenomic sequencing has permitted the identification of the pangolin-associated coronaviruses that belong to two sub-lineages of SARS-CoV-2-related coronaviruses, including one that exhibits strong similarity to SARS-CoV-2 in the receptor-binding domain. The discovery of multiple lineages of pangolin coronavirus and their similarity to SARSCoV-2 suggests that pangolins should be considered as possible hosts in the emergence of novel coronaviruses and should not be traded in any form to prevent zoonotic transmission (Lahm *et al.*, 2020).

I.4.3 Cultural importance

Pangolins are considered as a high cultural value animal amongst local communities living throughout present and historical ranges. In Southeast Nigeria, the white-bellied pangolin is reported to be used sometimes to mark and tattoo human skin during the initiation of young unmarried women in some bush hamlets (Angelici *et al.,* 1999 cited by Kingdon & Hoffmann, 2013). The giant pangolin was considered a totemic animal and was formerly protected in some areas (e.g., in Olugave Clan in Buganda). But such taboos and local protection afforded to this animal by totems in West Côte d'Ivoire have been largely broken down, resulting in increasing hunting pressure (Kingdon & Hoffmann, 2013). In Cameroon, pangolin scales were once used as armor for warfare and as false nails for fashion. They are also perceived as conferring some protection against evil. Pangolins are used as spiritual remedies and as omens to protect people or bestow good fortune or heal and ward off evil. In Benin, the scales of the white-bellied pangolin are used to prevent accidents and provide protection against gunshot or knife wounds (Soewu *et al.*, 2020). Pangolins are also perceived as having a high cultural value in some traditional practices such as the Lele pangolin cult in the Republic Democratic of Congo mostly directed towards fertility, good hunting, and the suppression of sorcery. Pangolins are also used as paradigms of symbolic significance, predictors and in ritual sacrifice, and their products are used in magic. (Soewu *et al*., 2020).

Pangolins are perceived to have a good taste as meat and have high economical value. They are frequently recorded among the main species in studies of bushmeat taste preferences. In Cameroon, Infield (1988) reported that around Korup National Park pangolin meat is highly valued. Bobo & Kamgaing (2011) found white-bellied pangolins to be the second most commonly eaten animal in villages northeast of Korup National Park.

I.5 Pangolin conservation

I.5.1 Threats of pangolins

Pangolins’ poaching to supply intercontinental trade of scales has been identified to be the heaviest threat to all pangolin species. The black-bellied pangolin (*Phataginus tetradactyla*) is hunted for the local consumption of its meat and its scales which are used for cultural and ethno-medicinal purposes, including in traditional African pharmacopeias (Bräutigam *et al.,* 1994). The African long-tailed pangolins have been recorded in international trade many years ago (Bräutigam *et al.,* 1994). According to CITES trade reports of the period 1996 to 2011, seizures of pangolins included 40 specimens of alive individuals exported and the number of pangolins seized has unceasingly increased. In June 2008, five specimens of *Phataginus tetradactyla* from the Central African Republic were seized in Paris (Chaber *et al.,* 2010). Natural threats to pangolins include predation from leopards, *Panthera pardus* (Linnaeus, 1758), chimpanzees, *Pan troglodytes* (Blumenbach, 1775), large eagles, pythons, and mobbing birds are additional threats (Carpaneto & Germi, 1989).

The white-bellied pangolin (*Phataginus tricuspis*) is widely exploited for the illegal international trade of scales and meat for local consumption. This species is subjected to widespread and intensive exploitation for bushmeat and traditional medicine use (Anadu *et al.,* 1988; Fa *et al.,* 2000; Kingdon & Hoffmann, 2013). It is the most prevalent pangolin species sold in African bushmeat markets (Bräutigam *et al.,* 1994). In Cameroon, the white-bellied pangolin has been classified consecutively as the fourth (Fa *et al.,* 2006) and fifth (Kümpel, 2006) most harvested mammal species. According to CITES trade reports from 1996 to 2011, Togo exported 30 specimens of live white-bellied pangolins and the number of pangolins seized is increasing perhaps for use in the zoo in the USA. Natural deaths of the white-bellied pangolin are due to predation from leopards (Henschel *et al.,* 2005; Henschel *et al.,* 2011), chimpanzees, African golden cats, *Profelis aurata,* Africa rock pythons, *Python sebae* (Gmelin, 1789*),* jackals (*Canis* spp.), ratels, *Mellivora capensis* (Schreber, 1776), and large owls (Carpaneto & Germi, 1989). In Ghana, Ixodid ticks such as *Amblyoma compressum* (Macalister, 1872) and *Haemaphysalis parmata* are reported as white-bellied pangolin ecto-parasites (Ntiomoa-Baidu *et al.*, 2005).

The giant pangolin (*Smutsia gigantea*) is highly coveted by wildlife traffickers due to its large scales' size. It is subjected to wide and intensive exploitation for bushmeat and traditional medicine use (Anadu *et al.,* 1998; Fa *et al.*, 2000; Kingdon & Hoffmann, 2013). In 2004, it was the most prevalent species exploited with 5,019 kg of scales harvested in terms of biomass, 2,053 kg of white-bellied pangolin, and 3,355 kg of black-bellied pangolin from five markets in Gabon (Kingdon & Hoffmann, 2013). Today, literally tons of giant pangolin scales are being seized in Asia in containers arriving from Central and West Africa. The predators of giant pangolins include leopards *Panthera pardus* (Linnaeus, 1758) (Henschel *et al.*, 2005), African rock pythons *Python sebae* (Gmelin, 1789), lions i.e *Panthera leo* (Linnaeus, 1758) (Challender *et al*., 2020), and crocodiles. Figure 10 shows individuals of pangolin killed for scales collection and bags of pangolin scales.

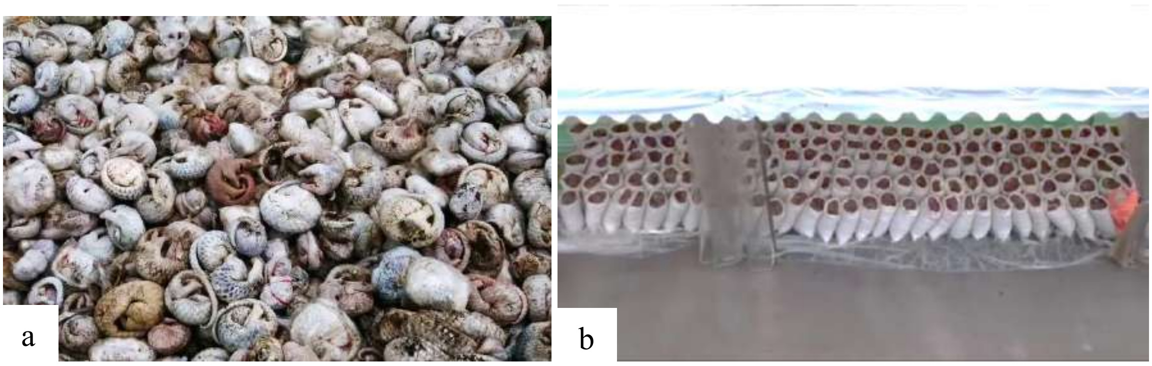


Figure 10: Evidence of threats faced by pangolin species throughout their range (a) individual of pangolin killed for scales collection and (b) bags of pangolin scales
Source: Film EYE OF THE PANGOLIN

The main threat that pangolins faced is the illegal trade of their meat and intercontinental trafficking of their scales. For the last decade, there have been a large number of seizures of living pangolins, pangolin meat, and derivatives (scales, bone) involving diverse countries, such as Angola, Cameroon (Table I), Central African Republic, Republic of Congo, Côte d'Ivoire, Guinea, Kenya, Mozambique, Nigeria, Sierra Leone, Uganda, Zimbabwe, Zambia, China, Vietnam, Malaysia, Myanmar, and Thailand. This illegal trade has continued despite the protection afforded to pangolins through home range countries' national legislation and CITES (Challender *et al.,* 2015; Waterman *et al.,* 2014). The illegal trade in pangolins has hugely increased in volume and activity over the last decade due to the demand for scales for Traditional Chinese Medicine (TCM) and de-scaled pangolins for meat consumption. Much of the demand has been fueled by TCM-pharmaceutical companies in China increasingly 'selling' the use of pangolin ingredients in processed TCM over the last decade. Pangolins are now the most heavily trafficked wild mammal by volume on the planet, with literally tons of scales representing thousands of individuals being regularly seized in Asia. In Central and West Africa, there are well-organized networks of hunters, loggers, middlemen, transporters, and wholesalers of scales who trafficked high volumes of scales to Asia facilitated by corrupt authorities and officials (TRAFFIC, 2019). These international organized crime syndicates are supported by and part of Asian illegal wildlife trade syndicates. Pangolin species everywhere are threatened by this massive trade and conservation action and information is needed now more than ever.

Table I: Seizures of pangolins and their body parts in Cameroon from January 2006 to June 2018

Year	Location	Genus	Item seized	Quantity	Additional items seized	Source
2007	Mezam	*Smutsia*	meat	-	Meat from chimpanzees and other protected species	LAGA
2008	Haut-Nyong	*Smutsia*	meat	-	2 tusks and meat of elephant and gorilla	LAGA
2009	Mfoundi	*Smutsia*	meat	-	Meat from the dwarf crocodile, potto, monkey, and gorilla	LAGA
2010	Dja-et-Lobo	*Smutsia*	meat	-	Chimpanzee, duiker and water chevrotain meat	LAGA
2012	Haut-Nyong	*Smutsia*	Whole animal	1	Other meat	LAGA
2013	Fako	*Smutsia*	Scales	7 sacs	-	LAGA
2013	Limbe, Fako	-	Scales	80 kg	-	EIA
2013	Mfoundi	-	Scales	7 sacs	Live forest tortoise	LAGA
2013	Mfoundi	*Smutsia*	Scales	44 kg	4 elephant tusks and 25 pieces of worked ivory	LAGA
2014	Mfoundi	*Smutsia*	Scales	4 bags	-	LAGA
2014	Yaounde, Mfoundi	-	Scales	120 kg	-	EIA
2014		-	Scales	150 kg	5 gorilla skulls, 7 chimpanzee skulls, elephant jawbone	EIA
2014	Kadey	*Smutsia*	Scales	>100 kg	Elephant, gorilla and chimpanzee bones	LAGA
2014	Noun	*Smutsia*	Scales	4 kg	Chimpanzee: 1 Live, 7 skulls and 30 hands	LAGA
2015	Yaounde, Mfoundi	*Smutsia*	Scales	100 kg	-	EIA
2015	**Near Deng Deng National Park**	***Smutsia***	**Scales**	**14 kg**	**-**	**EIA**
2015	**Bertoua, Lom-et-Djerem**	**-**	**Scales**	**200 kg**	**-**	**EIA**
2015	Bafoussam, Mifi	-	Whole	1	Olive baboon, porcupine, civet, and duiker meat	EIA
2015	-	-	-	-	-	EIA
2015	**Mbam-et-Kim**	***Smutsia***	**Scales and legs**	**4 legs**	**1 baby colobus monkey**	**LAGA**
2015	Mfoundi	*Smutsia*	Scales	114 kg	-	LAGA
2015	Kadey	Both	Scales	2.5 kg	2 Chimpanzee skulls	LAGA
2015	Mfoundi	Smutsia	Scales	2.5 kg	-	LAGA
2015	Mefou-et-Afamba	*Smutsia*	Scales	100 kg	-	LAGA
2015	**Lom-et-Djerem**	***Smutsia***	**Scales**	**15 kg**	**-**	**LAGA**

2016	**Bertoua, Lom-et-Djerem**	***Smutsia***	**Scales**	**200 kg**	**12 ivory tusks**	**LAGA**
2016	Nyong-et-Kelle	-	Scales	-	Sea turtle shells and chimpanzee skulls	LAGA
2016	-	*Smutsia*	Scales	-	-	LAGA
2016	-	-	Scales	128 kg	-	LAGA
2016	Yaounde airport, Mfoundi	-	Scales	670 kg	-	EIA
2016	Ngaoundal, Region of Adamaoua	-	Scales	128 kg	-	EIA
2017	Douala, Wouri	*Smutsia*	Scales	5 tonnes	-	EIA
2017	Messamena	-	Scales	94 kg	-	LAGA
2017	Yaounde, Mfoundi	-	Scales	45 kg	Leopard skin	LAGA
2017	Ebolowa, Mvila	-	Scales	35 kg	Baby chimpanzee	LAGA
2017	Yaounde, Mfoundi	-	Scales	41 kg	Baby mandrill	LAGA
2017	Ebolowa	-	Scales	50 kg	-	LAGA
2017	Bangangte, Nde	-	Scales	-	2 leopard skins	LAGA
2017	Sangmelima, Dja-et-Lobo	*Smutsia*	Scales	10.5 kg	4 ivory tusks	LAGA
2017	Douala, Wouri	-	Scales	128 kg	-	LAGA
2018	Ambam, Vallee-du-Ntem	-	Scales	80 kg	Baby chimpanzee	LAGA
2018	Betare Oya, Lom-et-Djerem	-	Scales	36.5 kg	6 hippopotamus teeth, 2 boa skins	LAGA
2018	Santchou, Menoua	-	Scales	-	Elephant bones, ivory	LAGA
2018	Doume, Haut-Nyong	-	Scales	35 kg	-	LAGA
2018	Douala airport		Scales	1000 kg	Ivory	Author search

LAGA= Last Great Ape Organization; EIA= Environmental Investigation Agency; The gray denotes seizures that occurred in the division and subdivision where this research thesis has been conducted.
Data source : Ingram *et al*. (2019a)

The number of animals per 1,000 kg scales has been estimated for each pangolin species by the Tikky Hywood Foundation. For white-bellied pangolin weighing 2 kg, the weight of scales represented by 30% of body weight is 600 g per animal, and **1,666 animals** are required **per 1,000 kg scales seized.** For the black-bellied pangolin weighing 2.2 kg, the weight of scales representing 30% of the body weight is 660 g per animal and 1,515 animals are required **per 1,000 kg scales seized.** The ground pangolin is 9.7 kg (Zimbabwean individuals Average), the weight of scales represented by 30% of body weight is 2,910 g per animal and **344 animals** are required **per 1,000 kg scales seized**. For a giant pangolin weighing 12 kg, the weight of scales represented by 30% of body weight is 3,600 g per animal and **277 animals** are required **per 1,000 kg scales seized** (TRAFFIC, 2019)**.**

I.5.2 Global conservation status of pangolins

Historically, *Phataginus tetradactyla* was listed as Least Concern (LC) by IUCN and placed in Appendix II of CITES (Kingdon & Hoffmann, 2013). Due to increasing threats, this species' conservation status was revised and upgraded and is now listed as Vulnerable (VU) on the IUCN Red List (Fig.11a; Ingram *et al.*, 2019b) and appears on the CITES Appendix I (CITES, 2017). Similarly, *Phataginus tricuspis* was previously considered as Near Threatened (NT) by IUCN and in Appendix II of CITES. The white-bellied pangolin species conservation status was revised and upgraded twice between 2017 and 2019 and is now listed as Endangered (EN) on the IUCN Red List (Fig. 11b; Pietersen *et al.*, 2019) and is CITES Appendix I (CITES, 2017). *Smutsia gigantea* was previously listed as Near Threatened (NT) by IUCN and in Appendix II of CITES. This species' conservation status was reviewed twice between 2017 and 2019 and is now listed as Endangered (EN) on the IUCN Red List of Threatened Taxa (Fig. 11b; Nixon *et al.*, 2019) and in CITES Appendix I (CITES, 2017).

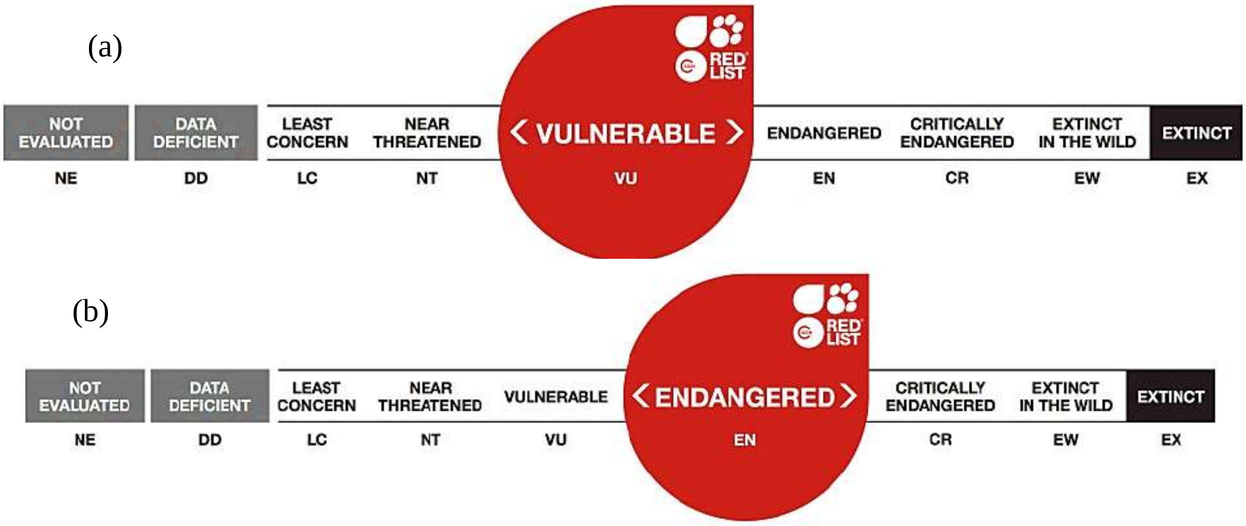


Figure 11: International Union of Nature Conservation (IUCN) species classification categories showing (a) the black-bellied pangolin and (b) white-bellied and giant pangolins level of classification
source: www.iucnredlist.org

I.5.3 Conservation efforts in Cameroon

According to the 1994 law of Wildlife Protection, all animal species found in Cameroon are classified in different levels of protection including Classes A, B, and C. The giant pangolin belongs to Class A (which is the highest level of protection) since 2006, and since 2017 the white-bellied and black-bellied pangolins were also upgraded to Class A (MINFOF, 2017). This means all forms of exploitation of all pangolin species are prohibited, including hunting, capture, killing, and trade (MINFOF, 2017). The 1994 wildlife law (Law N° 94/01 of the 20th January 1994 to lay down Forestry, Wildlife, and Fisheries regulations) is the main legal instrument that guides the protection of wildlife species and its decree of application (Decree N° 95/466/PM of 20th July 1995 lay down the conditions for the implementation of Wildlife Regulations), and several ministerial orders and decrees. Order N° 0648/MINFOF of 18th December 2006 accords different levels of protection to wildlife species and lists species of animals in classes A, B, and C based on the level of protection. Species from Class A are totally protected and cannot be hunted, captured, killed, or traded, while animals in Class B can be hunted, captured, or killed, subject to the granting of a hunting license. Class C species are partially protected and can be hunted, captured, or killed following conditions laid down by the government. The law states that the capture, keeping, or trade of totally protected species will result in a maximum sentence of three years in prison and/or a payment of between FCFA 3 million to 10 million.

In the 2006 list of protected species, only the giant pangolin was placed in Class A, while the white-bellied and black-bellied pangolins were placed in Class B. However, in 2013, a ministerial circular letter banned all trade of pangolin scales (Circular letter No.0153/LC/MINFOF/SG/DFAP/SDVEF of 27th June 2013, suspending the exportation of pangolins scales). Following the transfer of African pangolin species from CITES Appendix II to Appendix I, a Ministerial circular letter placed total protection on pangolins, hence, any capture, keeping, or trade-in of live or dead pangolins is strictly prohibited (Circular No.00017/LC/MINFOF/DFAP/SDVEF/ of 11th January 2017, relating to the exportation of Pangolins and Grey Parrots). Several NGOs, such as the World Wildlife Foundation, Zoological Society of London, Wildlife Conservation Society, and African Wildlife Foundation are working in collaboration with MINFOF to develop and improve conservation strategies for pangolins.

In February 2017, the government of Cameroon burnt 3 tons of pangolin scales to send a strong message that pangolin trafficking will not be tolerated within its territory. However, it is still common to find pangolins for sale along major highways, in wild meat markets, and in restaurants and to have them as part of the menu during celebrations in urban cities (Ichu *et al.*, 2017). Therefore, it is important to invest further in enforcing the laws protecting pangolins, raising awareness of pangolin protection measures, carrying out research, and other conservation efforts. Some recent efforts to conserve pangolins include: the MENTOR-POP & MENTOR-Bushmeat Fellowship Programs, the creation of the Pangolin Rescue and Rehabilitation Center and the Cameroon Pangolin Working Group (CPWG).

I.5.3.1 MENTOR-POP & MENTOR-Bushmeat Fellowship Programs

These programs were funded by the US Fish and Wildlife Service (USFWS) and executed as a collaborative agreement with the Zoological Society of London Cameroon (ZSL), with facilitation by the Cameroon Ministry of Forestry and Wildlife (MINFOF). MENTOR-POP (Progress On Pangolins) and MENTOR-Bushmeat were an 18 to the 24-month capacity-building professional program based in Yaoundé Cameroon from January 2016 to July 2017 for MENTOR-

POP and from March 2020 for MENTOR-Bushmeat. These programs aimed to develop the capacity of a team of conservation practitioners to design and execute conservation actions to address threats to Central Africa pangolin species. These programs have trained 17 sub-regional fellows in 1) conducting field assessments and monitoring of pangolin populations (see Ichu *et al*., 2017), 2) addressing the lack of appropriate legal systems, and the upsurge in international trafficking for luxury meat and medicinal use (Nebaneh *et al*., 2017), and 3) reducing bushmeat trade and the pangolin demand at local, national, regional and international levels (Nguyen *et al*., 2021).

I.5.3.2 Pangolin Rescue and Rehabilitation Center

The Tikki Hywood Foundation (THF) created in 1994 in Zimbabwe initiated the creation of a Pangolin Rescue and Rehabilitation Center (PRRC) in Cameroon which was officially opened on the 26th of November, 2019. Its role is to rescue pangolins confiscated by MINFOF, from the markets, villages, seizures, roadsides, and towns and then release them in adequately secured habitats in several national parks after a period of rehabilitation where feasible.

I.5.3.3 Cameroon Pangolin Working Group (CPWG)

The Cameroon Pangolin Working Group (CPWG) is a TRAFFIC facility initiative launched in February 2019 in Yaoundé, Cameroon. The CPWG is a collaborative platform for sharing knowledge, experience/expertise, advocacy, lessons, information, research, illegal trade, and conservation of pangolins with members in Cameroon and beyond. The group comprises government representatives, organizations, diplomatic missions, independent university researchers, etc, and will meet periodically to advance pangolin conservation in Cameroon.

I.5.3.4 The Last Great Ape Organization

The Last Great Ape Organization (LAGA) has been helping the Cameroon government in its wildlife law enforcement efforts by providing intelligence leading to arrests of pangolin traffickers and seizures of wildlife products. Since 2013, the organization has supported efforts leading to seizures of pangolin scales. Since the complete ban on both national and international trade in pangolins, increasing attention has been paid to the seizure of pangolin scales, arrests, and prosecution of culprits. By February 2019, the organization had assisted wildlife officials in the seizure of 7.5 tons of pangolin scales over the previous five years.

I.5.4 Conservation challenges

I.5.4.1 Limits to *in-situ* conservation

In situ conservation refers to all initiatives and actions (e.g., reintroduction of confiscated live pangolins) promoting the protection of the wild populations of pangolin species within its distribution ranges. The success of these initiatives requires prior understating of at least the ecological traits of the species. Ecological information on pangolins from field studies being continually provided for the three African pangolin species in Cameroon (Ichu *et al*., 2017, Bruce *et al*., 2018, TRAFFIC, 2019; Simo *et al*., 2020), it remains limited especially for the methods to assess and monitor populations, ex-situ and in situ conservation actions, and threats mitigation such as prevention of poaching in the wild, etc... However, monitoring pangolin population trends are vital to management/policy makers to take more informed decisions to conserve pangolins. While estimating pangolins' population remains a challenge and no data on population size exist, the quantity of seizures of pangolin scales, coupled with the high commercial value of the pangolin meat trade and the animals' low reproductive rate (Ganguly, 2013) suggests that pangolin populations are declining. Therefore, *in situ* conservation initiatives are urgent to help promote pangolins' survival.

I.5.4.2 Limits to *ex-situ* conservation initiatives

Ex-situ conservation refers to all initiatives and actions (e.g., captive breeding) promoting the protection of populations of pangolin species out of their wild habitats and distribution ranges. The high level of indiscriminate exploitation and range of unique ecological and physiological characteristics, including a low reproductive rate, make wild pangolin populations particularly vulnerable to extinction (Gaubert, 2011; Sodeinde & Adedipe, 1994). As such, there is an urgent need to consider *ex-situ* conservation as part of a holistic approach to conserving pangolins. However, despite a long history of keeping pangolins in captivity, with the first known captive records arising from a Buddhist monastery in Burma in 1859 (Yang *et al*., 2007), captive pangolins have historically faced high mortality rates, and maintaining healthy captive populations over the long term is challenging. Recently *ex-situ* conservation and a captive breeding program were successfully developed for the Sunda pangolin (Zhang *et al*., 2017). *Ex-situ* rearings are being explored worldwide for many species as a conservation action. However, the husbandry of seized animals is challenging for African pangolins. The diets of the white-bellied and black-bellied and giant pangolins are poorly known and little studied (Wicker et al., 2020). Dietary specializations often help drive the evolution of specialized biological and ecological traits, including social and population dynamics (Abba & Cassini, 2010).

Captive breeding of African pangolin species has not been attempted successfully. Pangolin diets make of ants and termites are very difficult to supply in sufficient quantities in captivity and constitute the principal challenge for captive populations (Chao *et al*., 2020; Challender *et al*., 2019). Diet has long been presumed to be the primary cause of pangolins' inability to thrive in captivity (Yang *et al*., 2007). Like most other insect-eating species, providing an artificial captive diet that is not only nutritionally complete but also palatable to the animals, has historically been one of the major challenges to keeping healthy pangolin populations alive in captivity (Yang *et al.*, 2007). In captivity, pangolin species have been fed with milk, meat, and eggs (Yang *et al.*, 2007) which are not consumed by pangolins in the wild. The poor record of keeping pangolins in captivity is correlated to the poor acceptance of captive diets and the digestive problems of the species (Zoo Biology, 2007).

I.5.4.3 Limit to law enforcement

In Cameroon, wildlife legislation accords the highest level of protection to all species of pangolins through ministerial order (MINFOF, 2020). However, the degree of protection on paper is not directly translated into action on the ground. There is insufficient motivation to clamp down on pangolin traders in some markets and this contributes to the booming illegal trade in pangolins (TRAFFIC, 2019).

Corruption is a major setback to effective wildlife law enforcement in Cameroon. When caught with illegal wildlife products (including pangolins and their derivatives), some traders in pangolin wild meat and high traffickers in pangolin scales attempt to bribe law enforcement officers (LAGA, 2017). Many pangolin-related judiciary offenses result in lenient court sentences, sometimes influenced by bribery, influence peddling, and other forms of corrupt practices (LAGA, 2017). Hence some offenders do not receive maximum sentences (LAGA, 2017, Nebaneh *et al.*, 2017). As a result of lenient sentences, coupled with insufficient follow-up to recover damages, some sentences are not severe enough to deter offenders from the trade in pangolins and their derivatives given the high potential profits from the trade.

I.5.4.4 Limited awareness raising

Currently, there are no established pangolin education/awareness-raising campaign programs ongoing in Cameroon, although some have taken place in the past. The MENTOR-POP Fellows and others pangolin defenders have organized activities annually to celebrate World Pangolin Day every second Saturday of February. These have included activities in rural communities around protected areas which are potential pangolin strongholds and in urban centers. Independent researchers and organizations (like the Tikki Hywood Foundation) have also conducted some pangolin education/awareness raising. However, many Cameroonians still do not understand why they should conserve small species like pangolins.

I.6 Influence of habitats on pangolins ecology

Apart from Swart *et al*. (1999), few studies have been conducted in Africa to assess the various environmental factors affecting pangolins in their habitats. For Asian pangolins, the occurrence of some species is greatly influenced by various habitat parameters such as canopy coverage, soil type, vegetation coverage, distance to a water source, and anthropogenic factors such as poaching (Bhandari & Chalise, 2014). Shrestha *et al.* (2021) have assessed habitat use and factors affecting pangolin species' habitat selection in Asia. The authors have shown that distance to settlement and to roads well as soil pH affect the habitat selection of pangolins (Shrestha *et al.*, 2021). Pangolin habitat use and characteristics of used or associated habitats appear to differ according to environmental conditions (Karawita *et al*., 2018), and identification of suitable habitats and potential distribution is essential for developing conservation strategies for these species (Katuwal *et al*., 2017).

I.7 Perceptions of pangolins conservation and local knowledge

Pangolin conservation is perceived differently and their knowledge differs among local people across their range and depends on the pangolin species. Local people perceived pangolins to be at risk of extinction and they are aware of the legislation protecting pangolin species (Nash *et al*., 2016, Ichu *et al*., 2017). A high level of people agreement towards law enforcement activities is often recorded in local communities. They usually propose strategies for pangolin conservation in their areas (van Vliet and Mbazza, 2011). However, some communities may not be motivated to conserve wildlife on which they rely as a primary source of animal protein because they do not have formal rights to benefit from wildlife (Wilkie *et al*., 2016). Moreover, pangolins are perceived as of have high nutritional and economical importance for the population and deserve protection. Local people may also want to preserve their wildlife from the increasing market demand from large towns, reducing the availability of meat for local consumption, but may lack the means to do so (Wilkie *et al*., 2016).

I.8 Review of pangolin surveys' methods

I.8.1 Local ecological knowledge-based surveys

Particularly for rare and elusive species such as pangolins, local ecological knowledge is an important tool to rapidly detect species presence and document cultural perception to inform conservation management decisions and has been increasingly applied (Sutherland *et al*., 2004; Segan *et al*., 2010; Golden *et al*., 2013; Nash *et al.*, 2016;). The LEK-based survey is an important complementary method to obtain useful data relevant to conservation, especially for large-bodied vertebrates, such as occurrence data and information on cultural use and local perspectives on conservation (Newton *et al*., 2008; Meijaard *et al*., 2011; Parry & Perez, 2015; Turvey *et al*., 2015). While, in some places, small- to medium-sized species of mammals are sometimes misidentified by respondents (Turvey *et al*., 2014), Nash *et al.* (2016) have recently used this method successfully to inform relevant ecological features of the Chinese pangolin (*Manis pentadactyla*).

I.8.2 Camera trap surveys

- **Population studies**

There are challenges relating to the accurate identification of pangolin presence signs comparable to other mammal species to confirm its presence, and evaluate the density of their population particularly when different species with similar behaviors are in the same locality (Ichu *et al*., 2017). For Example, the aardvark (*Orycteropus afer*) and African brush-tailed porcupine (*Atherurus africanus*) feeding signs can be similar to that of giant pangolin and white-bellied pangolin respectively. The secretive lifestyle of most species and their nocturnal, arboreal, and burrowing habits make observations very difficult (Wu et al., 2004,). Camera-traps are increasingly recommended for pangolin surveys (Willcox *et al*., 2019; Khadja *et al.*, 2019). Hence, camera-traps are an important tool for monitoring rare and cryptic species (Cutler & Swann, 1999). They offer a reliable and non-invasive method for detecting species' presence in the wild (Araujo & Chiarellio, 2005; Giman *et al*., 2007; Tobler *et al*., 2008; Bruce *et al*., 2018a). These sensors equipment provide verifiable records of data and samples of medium to large ground-dwelling mammals (Ahumada *et al*., 2019), including even arboreal pangolins, such as white-bellied pangolins (Bruce *et al*., 2018). Camera-traps allows one to calculate comparable trapping rates. Trapping rates have been used to determine a relative abundance index (RAI) with the assumption that a target species will trigger cameras in relation to their abundance (Tobler *et al*., 2008; Bruce *et al*., 2018) and to their frequency of activity at the placement site with the assumption that all other factors being equal. Pangolins are potentially well suited to camera trap monitoring because they are relatively large (>1 kg), endothermic (and therefore suitable for the passive infrared sensors most commonly used on camera traps), and most species are at least partially terrestrial (Khwaja et al., 2019).

- **Pangolin behavioral studies**

There are different methods of systematically collecting wildlife behavior data, ranging from the use of check sheets to handwritten or tape-recorded descriptions, and digital recording devices (Strier, 2018). Remote camera systems are one of the newest tools for behavioral research. They combine many of the advantages of traditional techniques while offering several improvements (Bridges & Noss, 2011). Although camera housing, sounds, and flashes associated with some camera systems could potentially modify behavior, the disturbance is likely to be less than would be expected if the researcher was present directly observing behavior (Griffiths & Van Schaik, 1993; Alexy *et al*., 2003; Bridges *et al*., 2004a). Foraging areas are places that provide food, water, or nutrients for animals and can provide insight into animal behavior and activity patterns. The feeding behavior of a single species can be assessed with camera-traps targeting likely feeding sites.

Photographs allow for estimates of the timing, duration, and frequency of visits (Claridge *et al.*, 2004). For example, camera-traps located near carcasses or fruiting trees may observe foraging behavior (Bridges & Noss, 2011) and seasonal changes in activity (Bridges *et al.*, 2004b).

I.8.3 Tracking and feeding activity observations

GPS-collar and Very High-Frequency Telemetry (VHFT) are used to study home range size (Pagès, 1975); behavioral ecology (Swart, 1996; Pietersen *et al.*, 2013). Data from direct observation of radio-tagged pangolin feeding activities are available for Temminck's pangolin (Pietersen *et al.*, 2016) and white-bellied pangolin (Pages, 1975) as well as some field observations. In these surveys, pangolins tagged with VHFT were tracked and after a pangolin had fed on the specific sites, a sample of the prey was collected and stored in absolute ethanol (Swart, 1996; Pietersen *et al.*, 2013). The content was microscopically compared to the reference collection of the surveyed sites and the prey selectivity was determined using Manly Selectivity Index following Manly *et al.* (2002). Swart *et al.* (1999) studied the dietary and foraging behavior of fifteen radio-tagged pangolins together with the community composition and occurrence of ants and termites in the arid zone habitat. Direct observations suggest that purported non-prey species are not consumed, possibly because they have chemical or mechanical defenses or gallery structures that make them unsuitable/inaccessible as preys (Swart, 1996).

I.8.4 Stomach or gut contents and scat analysis

Firstly, given the scarcity of pangolin dungs in the wild, and the dungs might be found sometimes already decayed leading to difficulty in the identification of the content. Secondly, pangolin species cannot be captured for regurgitation of the stomach contents for the moment because the protocol is lacking. Many authors rely on the stomachs of dead pangolins or scat content analysis to determine their diet compositions. This method contributed to identifying confidently the diet of several pangolin species through scat (Mahamood *et al.*, 2013) and stomach content (Gao, 1934; Minami, 1941; Coulson, 1989; Lee *et al.*, 2017; Ashokkumar *et al.*, 2017).

I.8.5 Stable isotope analysis of pangolin tissues

Stable isotope analysis is an alternative method to reconstruct animal diets and in particular to understand the assimilation of nutrients ingested (Ayliffe *et al.*, 2004; West *et al.*, 2006; Newsome *et al.*, 2007; Boecklen *et al.*, 2011). Different tissues of animals can provide information on the temporal variation of diets. Tissues characterized by rapid turnover rates (e.g., blood and liver) provide information on recent diets while tissues with slow turnover rates (e.g., bone apatite and scales) provide dietary information integrated over longer periods (Tieszen *et al.*, 1983; Tieszen & Fagre, 1993; Hilderbrand *et al.*, 1996). Inert tissues such as scales reflect the diet during the period that the tissue was grown, and as keratin is produced continuously it facilitates diachronic indication of diet variability (Ayliffe *et al*., 2004; West *et al*., 2006; Newsome *et al*., 2007). Pietersen *et al*. (2014) analyzed samples of livers and scales of Temmink's pangolin. The stable isotope data show that this pangolin species displayed a high degree of prey selectivity. However, stable isotope analysis was not able to infer the diet of pangolins as several non-prey species had similar isotopic values to prey species (Pietersen *et al*., 2014).

I.8.6 Habitat prey assemblages survey

Habitat prey assemblage surveys were conducted to assess the insect preys associated with pangolin habitats. The abundance and occurrence of insect preys in pangolin habitats, mainly ants and termites, were studied using pitfall and bait traps and hand-sampling (Swart, 1996; Li *et al.*, 2011; Pietersen *et al.*, 2016). Data on insects in habitats have been used to assess pangolin prey selectivity of some African pangolin species, the prey community assemblages, and availability as food for pangolins (Swart *et al*., 1999; Li *et al.*, 2011; Pietersen *et al.*, 2016). Li *et al.* (2011) conducted a termite survey in a Formosan Pangolin, *Manis pentadactyla* habitat for prey assemblages and food associated with the habitat. Termite samples were collected from soil, dead trees, decayed woods, and dead branches of living trees by using axes and aspirators or forceps.

I.8.6 Environmental DNA survey

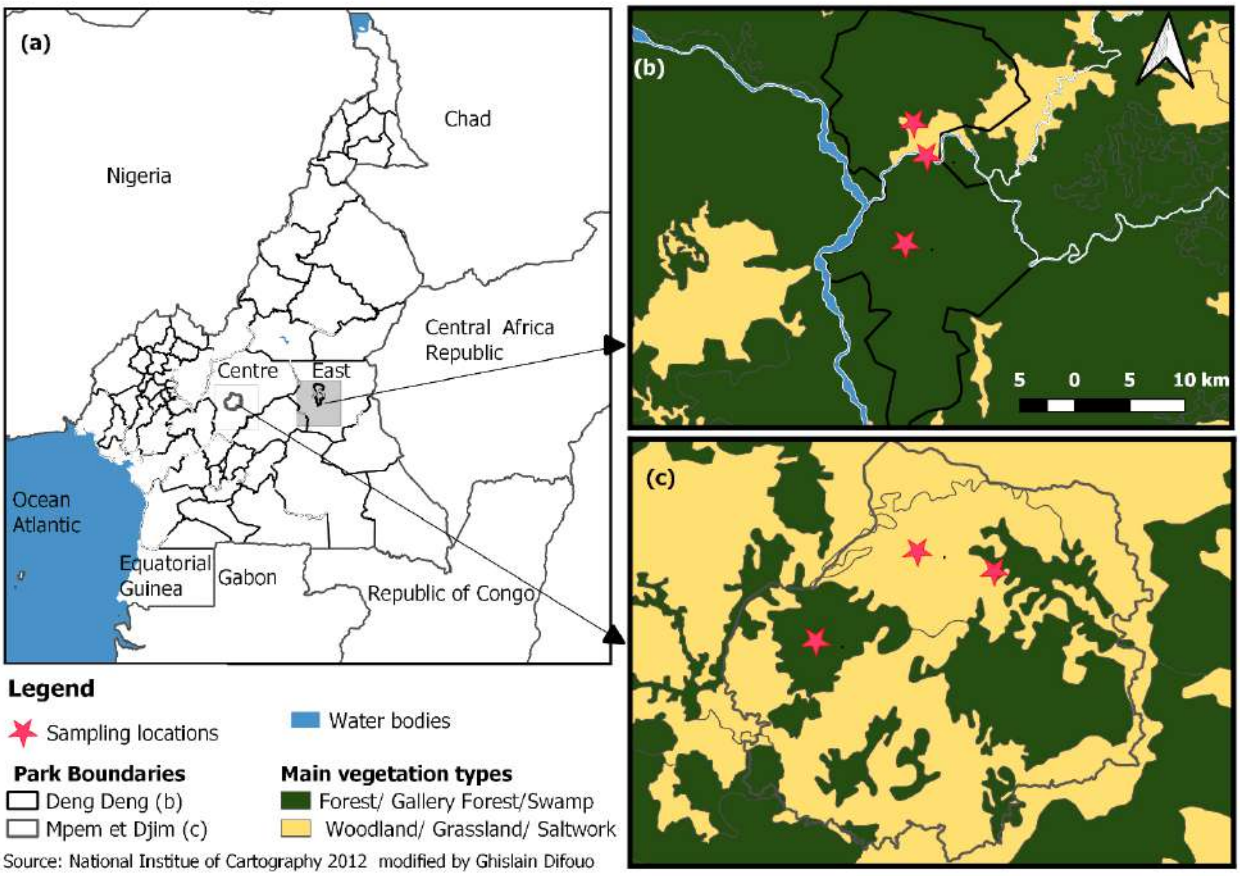
Environmental DNA (eDNA) was initially developed to detect aquatic species, but it has become a powerful tool to detect and monitor also terrestrial species (Jerde *et al*., 2013; Orzechowski *et al*., 2019; Katz *et al*., 2021; Leempoel *et al*., 2020). eDNA refers to nuclear or mitochondrial DNA that is released from an organism into the environment and can be accessed from the collection and/or filtration of nonbiological substrates (Ficetola *et al*., 2008, Pawlowski 2020). Common sources of eDNA include fur, feces, water, and recently soil (Leempoel *et al*., 2020). Recent evidence suggests that water-sourced eDNA can be more effective in developing species inventory lists at field sites than other commonly used methods like camera traps (Ishige *et al*., 2017). Pangolins use a long, sticky tongue to feed on ants and termites, and use their forefeet and claws to create and enhance burrows (Pagès 1970; Challender *et al*., 2019). During these activities, epidermal cells, saliva, urine, and feces can be shed into the soil allowing for detection using eDNA analysis from soil samples (Hoffman *et al*., 2020). eDNA sampling has been tested in Cameroon as a possible non-invasive technique to evaluate pangolin populations (Ichu, 2022). In the study, the three species of pangolin found in Cameroon were recorded through stream waters and soil samplings, although few records were obtained. The method was not appropriated to achieve our objectives and required future tests in various situations.

Chapter II:

Study sites, Materials and Methods

II.1 Study sites

The survey was carried out using two main techniques: socio-economic surveys through semi-structured questionnaire interviews and ecological field surveys. The ecological survey was carried out respectively in two national parks in the Centre and East Regions of Cameroon: Mpem et Djim National Park (MDNP) and Deng-Deng National Park (DDNP) (Fig. 12). These protected areas are located in the forest-savanna transition zone of Cameroon; this landscape extends from 4° to 6° latitude North and 11° to 16° longitude East in the sub-equatorial vegetation subset (Tsalefac *et al*., 2000). These parks were selected for this research because they are located in pangolins home range in Cameroon and pangolin scales have been seized around MDNP (Atagana, Pers. Comm.) and DDNP (Ingram *et al*., 2019a). Contrary to MDNP, DDNP has a development plan. We compared the role of different levels of conservation strategies implementation, and the impact of the different habitat types on pangolins ecology. Few surveys have been conducted in these protected areas. Except for faunal inventories that have been carried out in MDNP by MINFOF (2011, 2020), Atagana *et al.* (2018) have also inventoried bat communities in this protected area. In DDNP, Maisels *et al.* (2011) carried out field studies on gorillas, and Diangha (2015) surveyed mammals.



Source: National Institue of Cartography 2012 modified by Ghislain Difouo

Figure 12: Location of the surveyed sites (Mpem et Djim National Park and Deng-Deng National Park) in the Centre and East Regions of Cameroon. The location of the stars represents the sampling locations in the main habitat types of the parks. Source: National Institute of Cartography (INC 2012) modified.

II.1.1 Mpem et Djim National Park

Mpem et Djim National Park (MDNP) is located in the Central Region of Cameroon in the Mbam et Kim Division (5°–5°20' North / 11°30'–12° East; average altitude of 640 m; Fig. 12c) and covers 976 km^2. The MDNP was established by Decree No. 2004/0836 / PM of 12 May 2004 to extend the national network of protected areas (MINFOF, 2011). It is located in the Yoko sub-division, Mbam and Kim Division in the Central Region. It is largely encompassed by the loop formed by the rivers Mpem and Djim and their tributaries. Mpem and Djim rivers are the natural boundaries in the East, South, West, and much of the North. The other part of the North is bounded by a 5 km segment of land.

II.1.1.1 Climate

The MDNP is characterized by a transitional climate between the tropical and equatorial with four seasons: a long dry season lasting > four months (mid-November to mid-March), a short rainy season (mid-March to end of June), a short dry season (from July to August) and a long rainy season (September to mid-November) (Suchel, 1988; Tsalefac *et al.*, 2000). The mean annual rainfall ranges between 1,800 and 2,000 mm per year, while the annual temperature averages 22–29°C (Tsalefac *et al.*, 2003).

II.1.1.2 Soils

The soils in the MDNP zone are ferritic, hydromorphic, and saline soils. The park and the broader Yoko region have similar geology characteristics mainly consisting of metamorphic rocks whose principal minerals are gneisses, mica schists, and schists (MINFOF, 2011). The overall morphology is made up of elongated mounds, with peaks and with gently sloping slopes (slopes of around 5%), and the valleys are not very steep (MINFOF, 2011).

II.1.1.3 Hydrography

The hydrography of the MDNP consists mainly of two large rivers that surround the park, namely Mpem and Djim. These two rivers have their sources in the west of the Borough of Yoko and meet in the east of Ngoro (MINFOF, 2011). Other rivers include Meti, May, and Gimboon.

II.1.1.4 Vegetation types

The location of the park in a forest-savanna transition zone gives the national park a unique composition of flora and fauna. In the MDNP, the vegetation formations mostly include tropical forests, secondary forests, woodland and grassland savannas, and gallery forests (MINFOF, 2011; Fig. 12). The savanna's flora species include *Eupathorium odoratum* (Bokassa grass) and *Imperata cylindrica* which are dominant in the herbaceous stratum. The tree stratum is represented by *Albizzia* sp., *Lophira* sp. (savanna azobea), and *Ochroma africanus* as the main tree species. The forest tree species composition is typical of the rainforest with similar species to that of Deng Deng National Park, including iroko, sapelli, padouk, fraké, and other species (see MINFOF, 2011).

II.1.1.5 Mammal wildlife

The park harbors diverse large mammal species, including chimpanzee *Pan troglodytes* (Blumenbach, 1775), elephant *Loxodonta africana* (Blumenbach, 1797), african buffalo (*Syncerus caffer*), baboon *Papio anubis* (Lesson, 1827), pangolin spp. (*Phataginus* spp.), giant pangolin *Smutsia gigantea* (Illeger, 1815), red-river Hog *Potamochoerus porcus* (Linnaeus, 1758), giant hog *Hylochoerus meinertzhageni* Thomas, 1904, Water Hog *Phacochoerus aethiopicus* (Pallas, 1766), bongo *Tragelaphus euryceros* (Ogilby, 1837), spotted-nosed guenon *Cercopithecus nictitans* (Linnaeus, 1766), guereza colobus *Colobus guereza* Rüppell, 1835, mustached guenon *Cercopithecus cephus* (Linnaeus, 1758), bleu duiker *Philantomba monticola* (Thunberg, 1789), yellow-backed duiker *Cephalophus sylvicultor* (Afzelius, 1815), bay duiker *Cephalophus dorsalis* Gray, 1846, red-flanked duiker *Cephalophus rufilatus* Gray, 1846, sitatunga *Tragelaphus spekei* (Speke, 1863), bushbuck *Tragelaphus scriptus* Pallas, 1766, spot-necked otter *Lutra maculicollis* Pocock, 1921, and aardvark *Orycteropus afer* Pallas, 1766 (MINFOF, 2011).

II.1.1.6 Demography and ethnicity

There is no detailed survey estimating the population size around MDNP. Several villages are located around MDNP, the most important in terms of development is Linté (north-west) then other townships such as Ntui (south-east), Ngoro, and Mbangassina (south-west) are located far from the park. The native tribes are Baboute and Baveck. The non-native ethnics are Eton, Manguissa, and Haoussa who live from agriculture, extensive cattle and goat rearing, hunting, and gathering (MINFOF, 2011).

II.1.1.7 Socio-economic activities and landuse

The population living around MDNP are estimated to be approximately 30 000 inhabitants distributed in 6,000 households in four subdivisions namely, Mbangassina, Ngoro, Ntui and Yoko. The population size of the main township is about 14,000 persons in Voundou (Nzie, 2021). Farming is the main activity of the indigenous people of the MDNP (BRLi *et al*., 2022). Land slashed and burned for crop cultivation is widely practiced in the area. Food crops such as cassava, plantain, cocoyam, banana, maize, peanut, cucumber, okra, sweet potatoes, palm oil and pepper are cultivated mainly for household consumption. Cocoa is one of the main economic crops around MDNP, the yield is collected by a middleman who sold further in large markets such as Ntui, Bafia (GIZ, 2019). In Nguila village (east), there is a massive penetration of people from the department of Lékié who settle for the cultivation of cocoa, pineapples, and plantains. A part of these populations lives from petty trade (MINFOF, 2011; BRLi *et al*., 2022). Bushmeat is an essential source of protein and is among the main source of income. The meat is acquired through hunting and poaching. The main buyers of bushmeat are middlemen from neighboring cities who buy bushmeat mainly and retail in the urban markets in Bertoua, Yaoundé (MINFOF, 2011).

II.1.2 Deng -Deng National Park

Deng-Deng National Park (DDNP) was created by the Prime Ministerial decree N° 2010/0482 PM of 18 March 2010. DDNP is located in the East Region of Cameroon, precisely in the Lom and Djerem Division (5° 5’ to 5° 25’ North and 13° 23’ to 13° 34’ East, average altitude of 703 m), covers a 682 km^2 in the North-Eastern part of the lower Guinean forest. The Park is bounded by the Lom and Pangar Rivers to the east, a segment of the Cameroon railway line and settlement (villages) to the west by a continuous stretch of natural forest and savanna mosaic to the north, and by roads and settlement to the south.

II.1.2.1 Climate

Deng-Deng National Park is characterized by a tropical to equatorial transition climate with annual rainfall averaging 1,500–1,600 mm per year (Tsalefac *et al.*, 2000). It is a zone where is operated the transition between the tropical climate in the south the and sub-equatorial climate in the north (Suchel, 1988). The park has two dry and two rainy seasons of unequal periods (great dry and rainy seasons and small dry and rainy seasons). The mean annual temperature of the park is 23°C (Tsalefac *et al.*, 2003).

II.1.2.2 Soils

The park consists largely of flat and gently rolling terrain. The slope can be high at some points and the elevation within the park varies from 600 m in the south to 900 m in the north (Tsalefac *et al.*, 2000). The soil structure is variable with granitic and basalt rock dominating in the north and northeast corners of the park (Fotso *et al.*, 2002).

II.1.2.3 Hydrography

Deng Deng National Park hydro-resources form a significant network of rivers. These rivers include Muyual, Mbanpkwa, Mbactoua, and Mbibetana which flow throughout the year. These streams discharge into River Lom which empties into the Sanaga River. River Lom is the main river dividing the park into two sectors (northern and southern sectors). It forms a branch with a neighboring river called Pangar. Both rivers join at the site of the hydroelectric dam Lom-hangar construction project (Fotso *et al.*, 2002).

II.1.2.4 Vegetation types

Deng-Deng National Park belongs to the forest-savanna transition zone located in the north of the Guinean forest block (Letouzey, 1985), the largest in Central Africa and the south of the Adamaoua plateau (Tsalefac *et al*., 2000). The vegetation is both dense evergreen and semi-deciduous rainforest (Fotso *et al.*, 2002), mixed with patches of wooded and grassland savanna in the northern zone. Its location at latitude 32 in a forest-savanna transition zone (Dames & Moore, 1999), makes the park’s flora unique with both savanna and forest species. Habitat types include near primary forest, secondary forest, gallery forest, swamp, woodland savanna, and grassland savanna, with the dense forest covering 90.5% of the park (Fig. 12) (Diangha, 2015). The park’s forest flora is dominated by *Triplochiton scleroxylon* (Sterculiaceae) known commonly as”ayous“. It is commercially valuable and heavily exploited throughout its range in the East Region. Other trees of economic importance include *Entandophragma cylindricum* (“sapelli‟), *Terminalia superba* (“frake‟), *Entandophragma utile* (“sipo”) *Erythrophleum suaveolens* (“tali‟), *Eribroma oblonga* (“èyong‟*), Guarea cedrata* (“bosse‟), *Pterocarpus soyauxii* (“padouk”, *Xylopia aethiopica,* and *Enantia chlorantha*. The savanna flora, described by Diangha (2015), includes *Terminalia glauscesens, Hymenocardia* sp., *Vitex doniana, Monotes kerstingii, Piliostigma thonningii, Lohpira lanceolata, Prosopis africana, Lannea fructicosa*, and *Imperata cylindrica.*

II.1.2.5 Mammal wildlife

At least 40 large mammal species have been recorded in this park including vulnerable wildlife species, such as chimpanzee *Pan troglodytes*, west land gorilla *Gorilla gorilla gorilla* (Savage, 1847), bongo *Tragelaphus euryceros*, and sitatunga *Tragelaphus spekei*. Other mammals are monkeys such as spotted-nosed guenon *Cercopithecus nictitans*, guereza colobus *Colobus guereza*, and ungulates including buffalo *Syncerus caffer* (Sparrman, 1779), bay duiker *Cephalophus dorsalis*, blue duiker *Philantomba monticola*, yellow-backed duiker *Cephalophus silvicultor,* and red-flanked duiker *Cephalophus rufilatus*. The water-dwelling mammals, including hippopotamus *Hippopotamus amphibius* Linnaeus, 1758 and swamp otters are also present (Fotso *et al*., 2002; Maisels *et al.*, 2011). Deng-Deng National Park's biodiversity is highly threatened by surrounding operations of logging, petrol pipeline (Chad-Cameroon) and hydroelectricity dams Lom-Pangar, the national railway, and the hunting exerted by the growing number of people working these industries as well as the local communities.

II.1.2.6 Demography and Ethnicity

There is no published survey on the density of the human population living around DDNP. However, coarse estimation from the Electricity Development Corporation (EDC) suggests small population sizes in the villages around this park. The population size of the main village is about 574 persons in *Tête d'éléphant* (EDC, 2011, Diangha, 2015). The population density was estimated to be approximately 1300 inhabitants in 16 villages (Fotso *et al*., 2002). The main inhabitants are from relatively big villages located along the main road and railway like Deng Deng (about 250), Mbaki II (350), Goyoum (400) and *Tête d'éléphant* (574) are higher (EDC, 2011, Fotso *et al.,* 2002). The indigenous population in the villages adjacent to the park belongs to four ethnic groups *Képéré, Bobolis, Pols,* and *Gbaya* (Fotso *et al.*, 2002).

II.1.2.7 Socio-economic activities

The main activity of indigenous people living around DDNP is subsistence agriculture (WCS, 2008). Food crops are cultivated mainly for household consumption and sale. Another source of income for indigenous people is the rearing of livestock and poultry. Local breeding of animals includes goats, sheep, pigs, and fowls reared for subsistence, and also for sale to raise household income (GVC, 2007). Local people’s unsatisfaction with the protein supply driven by the high cost of domestic livestock and the lack of cheaper alternative sources of protein has increased the extraction of resources from the park and surrounding forest (GVC, 2007). Bush-meat resources mainly acquired through hunting and poaching are an essential source of protein and are among the main source of income (GVC, 2007). Hunting activity employed traditional trapping techniques but with the increasing demand for bushmeat, modern techniques requiring the use of snares and rifles are now being used for hunting especially when primates are also targeted. Buyers of bushmeat include residents who buy for consumption and middlemen from neighboring cities who on the other hand buy mainly for sale in the urban markets (Fotso *et al*., 2002).

Fishing products are another source of protein and income for the local population around DDNP. It is done on the main river Lom, using floating nets placed in lines and small streams like Mouyal, Mbactoua, and Mbibetana. Large quantities of fish are harvested and smoked along the banks of the river from where they are then transported by head or as backloads to the village. Smoked or fresh fish is sold to residents for home consumption or citizen of Bertoua, Yaoundé, and their middlemen who sell in neighboring urban markets. Non-permanent activities include petty businesses such as provision stores in big villages; small restaurants and off-license bars. External bodies such as logging companies, and pipeline and hydroelectric dam construction companies provide temporary employment and income to some residents around the park area (Diangha, 2015).

II.1.2.8 Traditional land uses and resources

Land uses in DDNP are dominated by farming lands (Diangha, 2015). Shifting cultivation of large areas of land slashed and burned for crop cultivation and intercropping are widely practiced in the area. Food crops such as cassava, plantain, cocoyam, banana, maize, peanut, cucumber, okra, and pepper are cultivated mainly for household consumption. However, groundnuts and cucumbers are cultivated for sale (GVC, 2007). Coffee is the major economic crop in the area but is farmed by few people likely due to market failures associated with low prices (Fotso *et al*., 2002).

II.2 Materials and Methods

II.2.1 Local Ecological Knowledge surveys

II.2.1.1 Questionnaire survey

II.2.1.1.1 Survey design: Villages and respondents' selection

A questionnaire survey was carried out between March 8–16th, 2018 at DDNP, and from August 21 to September 3, 2018, at MDNP. Following Nash *et al.* (2016), 20 villages (Fig. 13) that were 1) within a radius of 7 km from each national park were selected randomly and 2) safe to visit at the time of the survey. Using the snowball sampling technique to identify respondents, local guides and translators introduced us to local people believed to have good Local Ecological Knowledge (LEK; Ichu *et al*., 2017) and enabled us to identify people of less than ten years of permanent residency in the villages. The sample size was calculated and estimated to be approximately (n=500 individuals). In each village, we conducted interviews with at least ten people, when possible, to allow for adequate response saturation levels (Nash *et al*., 2016; White *et al*., 2005). Figure 13 shows the locations of the surveyed villages and forest offices surrounding MDNP and DDNP in Central and East Regions.

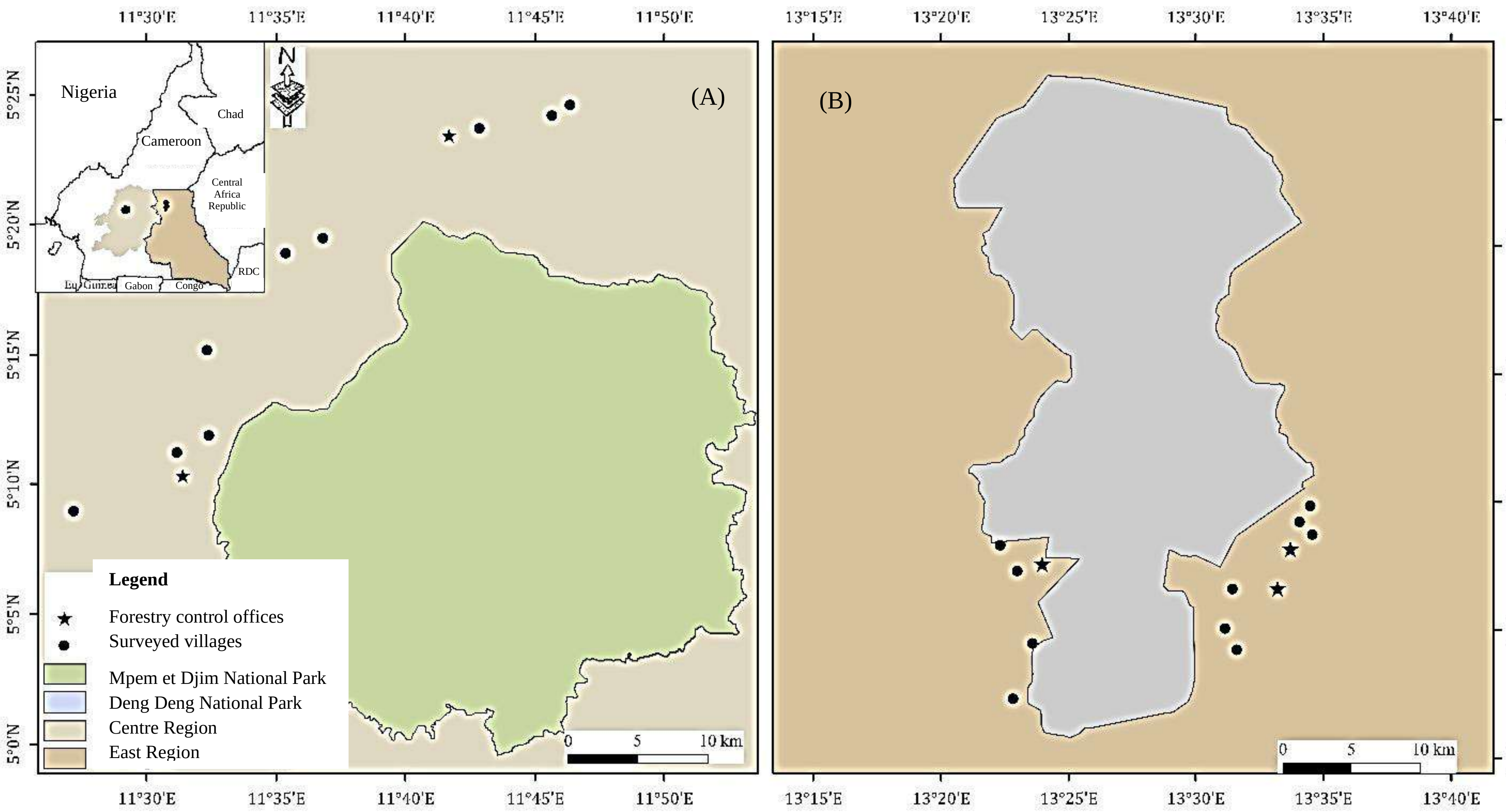


Figure 13: Locations of the surveyed villages and forest offices surrounding MDNP (A) and DDNP (B) in Central and East Regions, Cameroon Source: Simo et al. (2023).

Table II presents the surveyed villages with population size and number of respondents per village.

Table II: The surveyed villages with their population size and number of respondents

Parks	Villages	Population size	Number of respondents	Percentage (%)	Relative local percentage (%)
DDNP	Deng Deng	250	57	22.8	15.2
	Hona	-	4	-	1.07
	Lom-Pangar	180	41	22.77	10.93
	Goyoum	400	52	13	13.87
	Ouami	-	17	-	4.53
	Haman	-	6	-	1.6
	Lom	-	10	-	2.67
	Mansa	-	10	-	2.67
	Deoule	140	15	10.71	4
	Mbaki I	-	7	-	1.87
	Mbaki II	350	21	6	5.6
	Kambo-Cassi	-	12	-	3.2
MDNP	Mindou	300	16	5.33	4.27
	Mindja	400	13	3.25	3.47
	Kpa	10	3	30	0.8
	Mehou	50	5	10	1.33
	Linté	900	61	6.77	16.27
	Melen	31	7	22.58	1.87
	Mebi	38	7	18.42	1.87
	Ga'a	21	12	57.14	3.2
	Total	**3070**	**376**	12.24	**100**

Park codes are DDNP=Deng Deng National Paark; MDNP=Mpem et Djim National Park. The sample size includes only people known to have good knowledge of wildlife and not all the residents. Dashes denote villages whose population densities are not known and could not be estimated.
Source: DDNP (Fotso *et al.*, 2002) and MDNP (Nzie, 2021)

II.2.1.1.1 Pilot survey

A pre-survey was performed on February 2018 to train the research team of three interviewers, to standardize the survey approach, minimize variability, and evaluate the time involved to complete one interview. Each interview (lasting about one hour) was conducted as a proactive conversation, with one individual using a semi-structured questionnaire (see Appendix 1) including both open-ended and close-ended questions (Boakye *et al.*, 2015; Ichu *et al.*, 2017; Nash *et al.*, 2016).

II.2.1.1.2 Data collection

Ethical consideration

Authorization letters for this research were obtained from the Ministry of Scientific Research and Innovation (MINRESI), the University of Yaoundé 1, the government authorities (Divisional officers), and a research permit from MINFOF. Individual and community-level ethical considerations were made following the International Society of Ethnobiology (ISE) Code of Ethics (ISE, 2006) when possible, as follows. The survey team first introduced themselves to each surveyed village chief (traditional authorities) and then asked permission to conduct the study, presenting our institutional affiliation, and authorization letters to inform the chief of the survey objectives, benefits, and study period. After agreeing to take part, the chief usually informed the whole village of our presence. Free Prior and Informed Consent was obtained from all survey participants. Each interviewee's prior informed consent was obtained verbally (Akrim *et al*., 2017). Before each interview, respondents (all above 19 years old) were informed about the survey objectives, the fact that they would remain anonymous on the questionnaire, and, if necessary, were informed about the respect of the Law N°91/023 (1991) that stipulating that information collected from the survey questionnaire could not be used as a means of retaliation. Respondents were informed that their participation was completely voluntary and that they could abandon the interview at any point if they felt uncomfortable with questions. Questions were reformulated if respondents were not sure of the exact meaning and we asked for clarification of answers, where necessary, to ensure the accuracy of the information.

The questionnaire first addressed the demographic information (e.g., sex, age) of the respondents. They were then asked to identify a series of animal photos by name (in French or their local language). A negative control photo of a brown bear (*Ursus arctos* Linnaeus, 1758) that was not native to Africa was used to check for response reliability (following Turvey *et al*., 2014; Nash *et al*., 2016; Ichu *et al*., 2017). Subsequently, photos of an African Golden cat, *Caracal aurata* (Temminck, 1825), and giant, black-bellied, and white-bellied pangolins were used as positive controls. The response *petit pangolin* was considered as the correct name for both white-bellied and black-bellied pangolins. For each species, respondents were then asked whether they had seen each animal before, if so, they were asked when and where they had seen the species and when they had seen each species for the last time. Respondents were also asked about their perception of pangolin ecology including the pangolin habitat and diet preferences (see Appendix 1).

II.2.2 Field ecological studies

II.2.2.1 Pangolin behavior in habitat types

II.2.2.1.1 Classification of vegetation formations

II.2.2.1.1.1 Transects establishment

Before field trips, line transects were pre-established on a map using QGIS. They were arranged in each park to cover the different landscapes of the protected areas. In each national park, 15 line transects of 2 km were established with 1 km recces between two consecutive transects and 2 km recces between transects of different tidy (orderly) (Figs. 13a,b). On the field, the transects were cut following defined compass bearings carefully oriented to set considerations including park boundaries, elevation, and drainage following the protocol from Diangha (2015). Transects were cut and walked by survey teams of four persons, consisting of one compass bearer ("macheteur" or cutter), two observers of feeding sites, including a data collector, and one termite sampler. Transects were opened by a cutter, immediately followed by a researcher charged to control the azimuth constancy using a SUHUNTO compass and the distance covered using a handheld GPS Garmin 64S and record the paths followed. These were followed by the termite sampler and the person looking for pangolin feeding signs to install camera traps. During the walk along the transect, a total of eight waypoints (geographical coordinates) were recorded after each 250 m corresponding to the number of vegetation formations described per transect using a pre-established sheet of habitat description (see Appendix 2). The vegetation formations were categorized and classified following Nguenang & Dupain (2002).

II.2.2.1.1.2 Habitat characterization

Habitat is a physical space within which the animal lives, and the abiotic and biotic entities in that space" (Morrison & Hall, 2002). Habitat was defined as a vegetation formation following Tews *et al.* (2004). In this study, the physiognomic characteristics of each vegetation formation were described and several parameters such as altitude which was recorded with a Geographical Position System (GPS Garmin 64S); the slope and canopy cover percentages, undergrowth visibility, and vegetation composition (herbs, lianas, and shrubs) were recorded according to the protocol adapted from Bhandari & Chalise (2014). The slope at each location of each vegetation formation was classified into different levels from moderate slope to very steep as follows: 0 = moderate; 1 = steep; 2 = very steep. The canopy cover was visually quantified by classifying the percentage of the sky closure by tree canopy foliage above the location in the following category: 0 = none, 1-25% = open, 25-50% = close, >50% = very close canopy cover. The undergrowth visibility defined as the average of the four cardinal points opened visible distance visually estimated in a radius of 15 m from the observatory was categorized according to the level of understory open as follows: <5 m = very close, 6-10 m = close, 11-15 m = open, >15 m = very open undergrowth (see supplementary material, a sheet of pre-established conventional code of vegetation for wildlife inventory ZSL, Appendix 2).

II.2.2.2 Survey of pangolin behavior

II.2.2.2.1 Pangolin presence

In this study, camera-traps were used to confirm the presence of pangolins and to document their feeding behavior and preference of habitat through images and videos.

II.2.2.2.1.1 Pre-planned camera-trap locations

Based on a map showing the vegetation structures and rivers of the protected areas, the camera-trap stations (GPS coordinates) were pre-established in the survey area using QGIS software before fieldwork. To guarantee camera stations' independency and to cover all the vegetation types of surveyed areas, camera-trap waypoints were positioned to make a grid in which the distance between two camera-traps along a 2 km line transect was established (Fig.14). A minimal distance of 4 km was left between the first camera-trap line of the grid and the protected area boundaries. All the pre-planned camera-trap coordinates employed a camera-trap identification code (CamID) downloaded in GPS. The camera-traps and their corresponding SD cards (8GB-16GB) were labeled with the station name. For example, CN01 indicates that the camera-trap was relabeled accordingly before there-establishment in each surveyed sector of the park. (C) number 01 is located in the northern (N) sector of the protected area. These preparation activities were done before each survey trip.

II.2.2.2.1.2 Placement sites and camera trap deployment

Once in the field, the team proceeded to the first camera-trap station by tracking its geographical coordinates with a GPS Garmin 64S and a compass Suhunto. The team then walked the transects or recces following the method described by Diangha (2015). At the camera trap preplanned station (in an approximately 200 m radius around the geographical coordinate point), the local guides and the researchers searched for one of the pre-defined following placement targets. The potential sites of pangolin feeding activities were targeted (Ancrenaz, 2012); based on the assumption that pangolins usually forage on these sites and may return regularly. The targets were chosen with the help of local guides (hunters) and, also based on community perception of pangolin activities obtained during the questionnaire survey. The camera target sites (respectively Fig 15 a,b,c,d,e) included (a) living burrows (LB) or nest, (b) decaying trunks with termites (DTWT) (a sign of pangolin feeding activities being observable), (c) feeding signs on standing trunks (FSST), (d) termite mounds (TM) with excavation signs, feeding burrows (FB), (e) ground feeding sites (GFS, places showing many excavation signs of different ages), and also tree hollows (TH), and decaying trunks without termites (DTWtT). Before camera trap installation, the vegetation of the placement site in the camera zone was cleared carefully (without any great disturbance) to avoid false triggers from plant movements. Camera-traps were strapped on a tree at a height of 30-40 cm above the ground at 3-4 m from the target according to the protocol design by Ancrenaz (2012), then tested by Ichu *et al.* (2017) and later by Bruce *et al.* (2018a). This height is suitable to detect small mammals, such as pangolins.

After installation, the camera-trap location's physiognomic characteristics were described according to Bhandari & Chalise (2014). Camera-trap information, including date and time, geographical coordinates, habitat type and canopy cover, visibility, slope, altitude, and placement site were documented for each camera trap installation spot (one sheet used per camera-trap). Figure 14 shows the pre-planned camera trap stations and Fig. 15 shows the different placement site targets of camera traps.

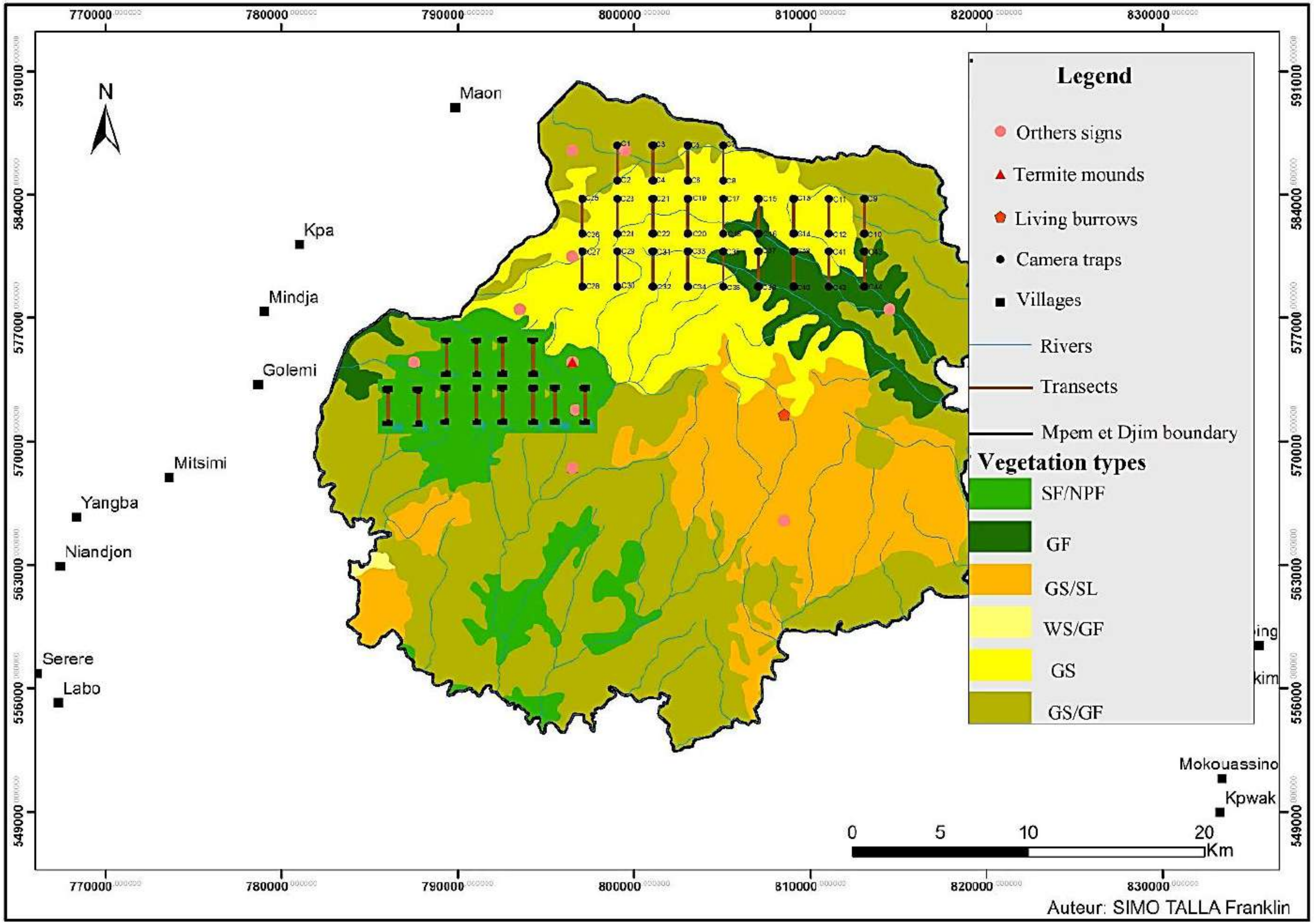


Figure 14: Example of pre-planned transects and camera trap stations during a field survey in DDNP. Habitat/vegetation codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp.

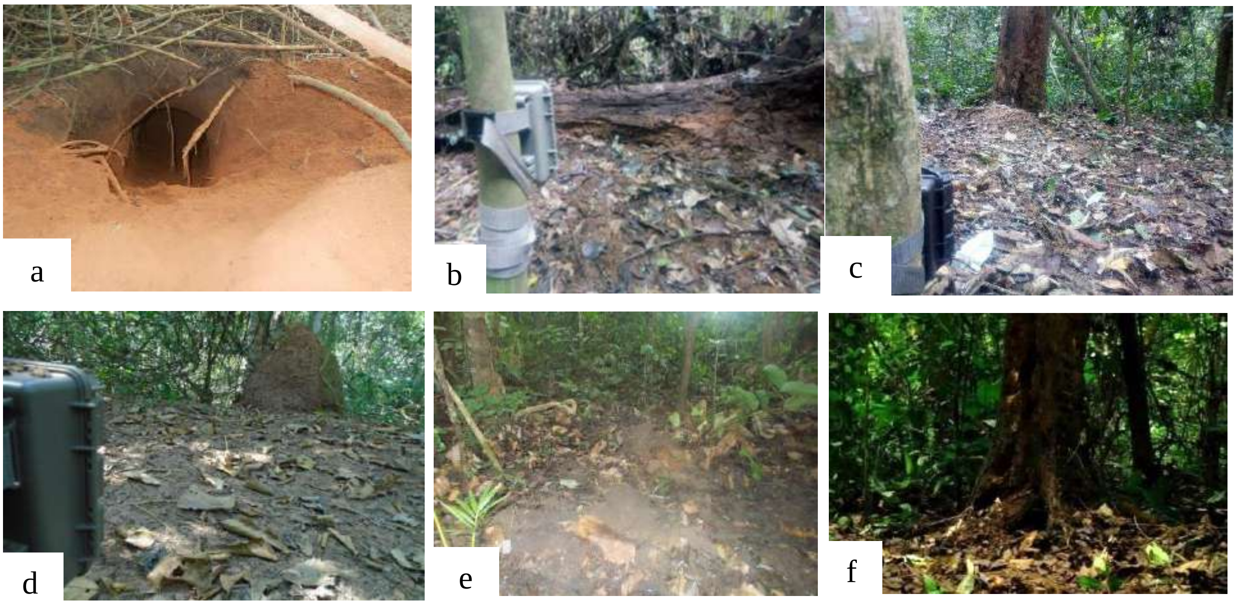
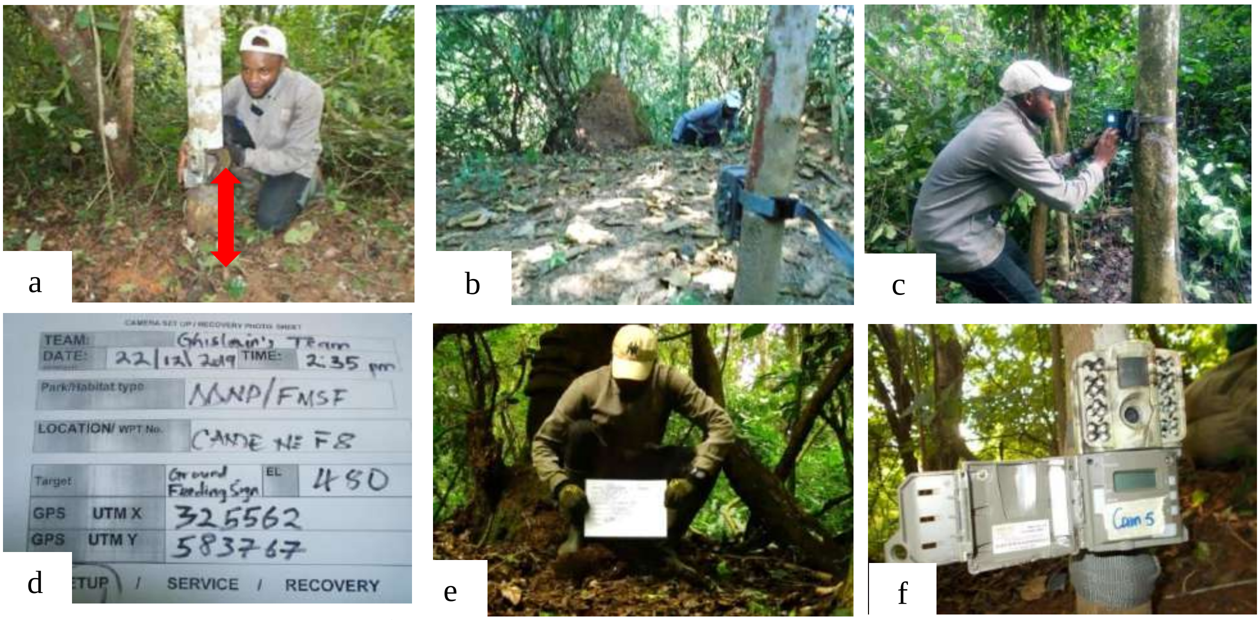


Figure 15: Different placement site as targets of camera traps a) living burrows, b) dead fallen trunks with the sign of feeding activities, c) feeding signs on the standing trunk, d) termite mound with excavation signs, e) feeding signs on the ground, and f) feeding signs on the standing trunk.

II.2.2.2.1.3 Camera-traps setting and operating test

Camera traps using eight Lithium Energizer AA batteries were used. This battery type worked very well for the survey and lasted for the duration of the camera trap study. We chose high-quality SANDISK memory cards which were 8 GB, 16 GB, and 32 GB. None of the memory cards was full of images when retrieved. Because pangolins are nocturnal, the white flash was used to enable more reliable identification. Video Mode or Hybrid Mode was chosen on Bushnell camera-traps to record videos of 20-second length with a sound option activated. Such settings of mixed video-photo Mode allow batteries to last longer. After installing the camera-trap (Fig.16a), camera operation was checked using the ‘walk test’ option (Fig.16b), to confirm that the camera sensor is working normally. Camera-traps were retrieved after at least 90 trap nights (3 months) and the SD card data was downloaded and stored in appropriate external and/or laptop driver disks. Camera-trap surveys were conducted in all savanna and forest habitat types during both the rainy and dry seasons.

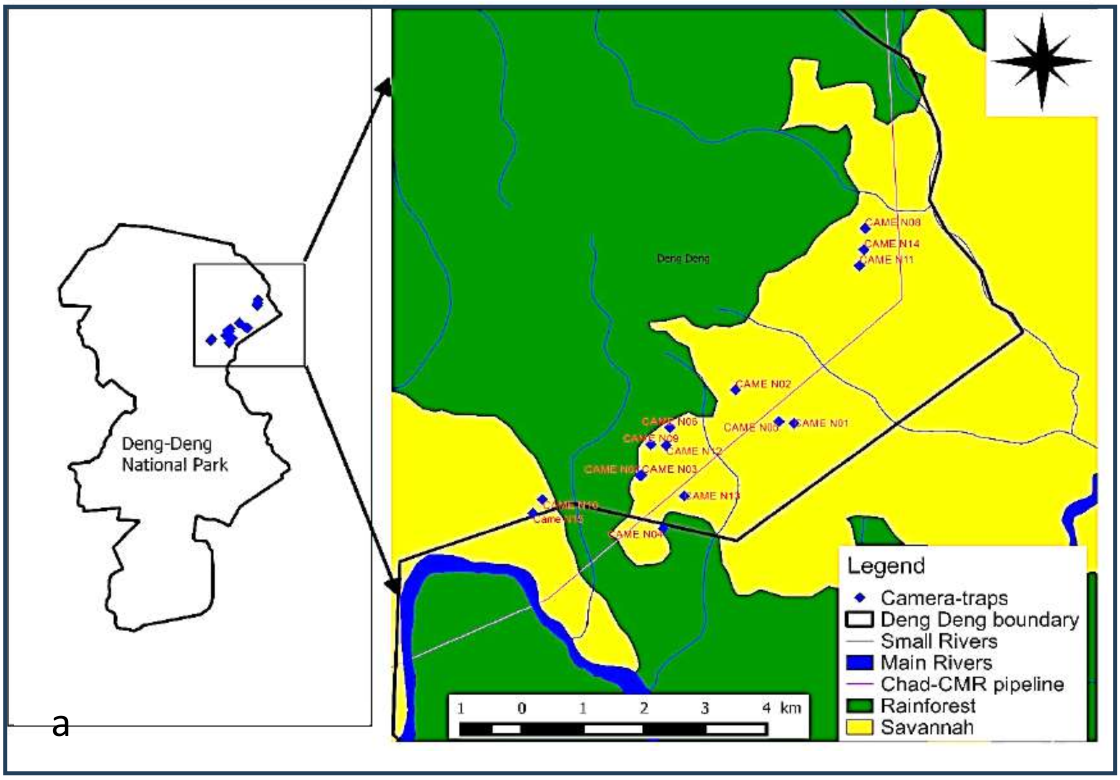
A total of 64 camera traps or camera stations were installed in the MDNP and 58 camera traps in the DDNP in both rainy and dry seasons. The camera-traps were of various marks and models, including Bushnell Essential E Brown 119837, Bushnell Trophy Cam HD 119873, Bushnell Trophy Camera Brown 119836, Cuddeback Xchange Color 1279, Cuddeback IR E2, Moltrie 30i (Fig. 16f). Each camera-trap was set to take three pictures per trigger with no delay between triggers (FAP=Fast As Possible for Cuddeback and 1-3 seconds per triggers for Bushnells according to models) to reduce the time between triggering of animal events. The image quality was 5 Mp for Cuddebacks and 8 Mp for Bushnells according to the standard minimal setting for useful image size (see the main used camera traps mark and model setting according to ZSL 2017, Appendix 4).



CAMERA SET UP / RECOVERY PHOTO SHEET
TEAM: Ghislain's Team
DATE: 22/12/2019 TIME: 2:35 pm
Park/Habitat type MNP/FMSF
LOCATION/ WPT No. CAME NE F8
Target Ground Feeding Sign EL 480
GPS UTM X 325562
GPS UTM Y 583767
TUP / SERVICE / RECOVERY

Figure 16: Field installation of camera traps with a) placement at 30 cm; b) investigator doing an operating test; c) setting camera strapped on tree; d) investigator taking the first photo; e) example of camera trap installation sheet; and f) Moltrie 30i camera model.

A map of the actual locations of the camera-traps was built (Fig. 17 a, b) and used to guide the team during the camera-traps retrieval trip. Photographed animals were identified down to the species level using the published book *Mammals of Africa* (Kingdon & Hoffmann, 2013) and other articles on wildlife in Cameroon (Crussack *et al*., 2015; Bruce *et al*., 2018b).



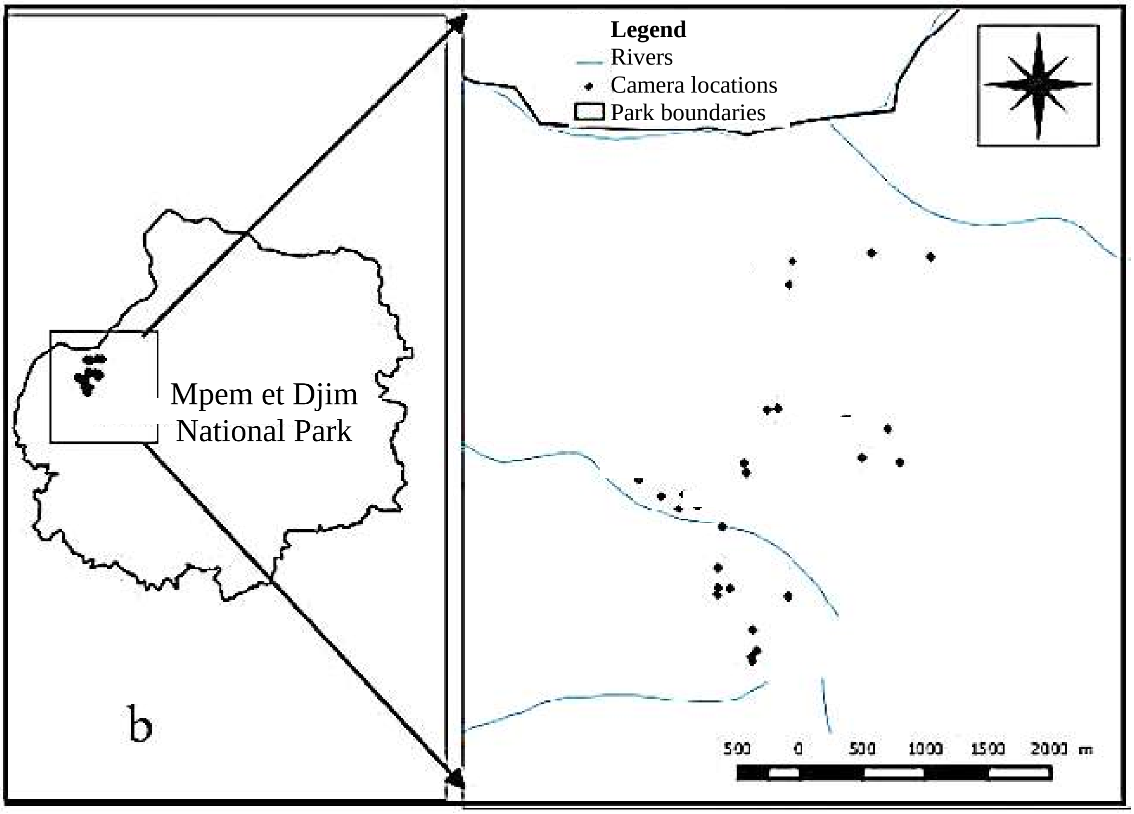


Figure 17: Camera trap station locations in (a) DDNP northern sector and (b) MDNP western sector.

II.2.2.2.2 Pangolin feeding behavior

In this study, camera-traps were used to characterize feeding behavior at suspected activity sites encountered in the surveyed areas during the dry and rainy seasons from April 2018 to April 2020. We assumed that pangolin activity at suspected feeding sites would enable us to collect enough observations and shed light on the feeding behavior of these furtive animals.

II.2.2.2.3 Habitat preference

Habitat preference is restricted to the consequence of the habitat selection process, resulting in the disproportional use of some resources over others (Morrison & Mathewson, 2015). Thus, habitat use is defined as the way an animal uses physical and biological components (i.e., resources) in a habitat (Morrison & Mathewson, 2015). Habitat use focuses on how an organism uses its habitat, not if they use an area or resource (Beyer *et al*., 2010). Usage is said to be selective if components are used disproportionately to their availability. Habitat selection is the hierarchical process of innate and learned decisions by an animal about where it should be across space and time to persist (Johnson, 1980). It is an evolutionary process based on fitness consequences that vary with differential resource use (Morris, 2011). In the two study localities, camera-traps were used to assess pangolin habitat preferences and its seasonal variation. Camera-traps produce data on the ecological behavior of pangolins if habitat features are considered in the sampling design (Wearn *et al*., 2013). Camera-traps were installed in all habitat types recorded, including woodland savannas, grassland savannas, gallery forests, near primary forests (old forest blocks), secondary forests, and swamps. The presence and relative use of each habitat type by pangolins were assessed using camera traps established in different vegetation formations in the surveyed areas.

II.2.2.3 Potential prey of pangolins

II.2.2.3.1 Common terrestrial ant communities

Samplings were conducted from 14th April 2018 to 25th April 2020 during the major rainy and dry seasons in the forest and savanna zones of the two national parks. Ant and termite assemblage surveys were conducted to gain knowledge of the potential prey available in pangolin habitats. These insect communities were compared with those recorded from stomach and scat samples to assess pangolin prey preferences. Multiple sampling techniques including, pitfall traps, bait traps, and hand-sampling were used to sample ants following the protocols adopted by Delabie *et al.* (2000) and Bestelmeyer *et al*. (2000). Ants were collected in a total of six habitat types in both national parks including near primary forest (NPF), secondary forest (SF), gallery forest (GF), saltworks (SL), swamp (SW), woodland savanna (WS), and grassland savanna (GS) (following Nguenang & Dupain, 2002). Saltworks (SL) was sampled only in MDNP where it only occurred and swamp only in DDNP. The savanna zone of MDNP was not surveyed during the dry season because of intensive bushfires and seasonal variation was assessed only in DDNP.

II.2.2.3.1.1 Pitfall sampling for ants

Pitfall traps were used to collect diurnal and nocturnal species and were efficient in this survey for estimation of abundances and occurrences of foraging ants (Olson, 1991; Klimetzek & Pelz, 1992), although Groc *et al.* (2014) suggest that Dorylinae family, when captured in numerous, can create bias. Cursorial ants (soil surface dwelling ants) were sampled using pitfall traps on 100 m line transects established in each habitat type following White & Edwards (2000) and Deblauwe & Dekoninck (2007). Ten pitfall traps (10 cm deep x 10 cm wide) containing soapy water were placed along transects at 10 m intervals with a small amount of earth and leaves around the tube providing access to small ants following Olson (1991). Each transect of pitfalls was located at least 100 m from and roughly parallel to adjacent transects. The pitfalls were collected after 24 hours and the ants were stored in 90% ethanol.

II.2.2.3.1.2 Bait and hand sampling of ants

The Baits method was used to capture foraging ant species attracted to meat and oil according to the protocol from Bestelmeyer *et al*. (2000). We used sardine baits as a complementary method to sample diurnal cursorial and foraging ants. Two transects per habitat type were deployed, roughly parallel and 100 m apart (Fig.18a). Ten small baits of sardine fish and oil arranged on a piece of 10 x 10 cm white paper (Fig. 18c) were placed at 10 m intervals along a 100 m transect.

They were retrieved after 10 minutes and the attracted ants collected between 9:00 AM and 3:00 PM. Ants within a 50 cm radius around the baits were captured manually. Ants collected in the manual sampling were only used to record the presence of species and not used in abundance estimates. Ant samples were preserved in vials containing 90% ethanol. Overall, in each habitat type and for both pitfall and bait traps method during two seasons, 80-ant samples were collected, for a total of 560 samples for seven habitats per park (two transects per habitat type). Figure 18 shows the experimental design of ant sampling.

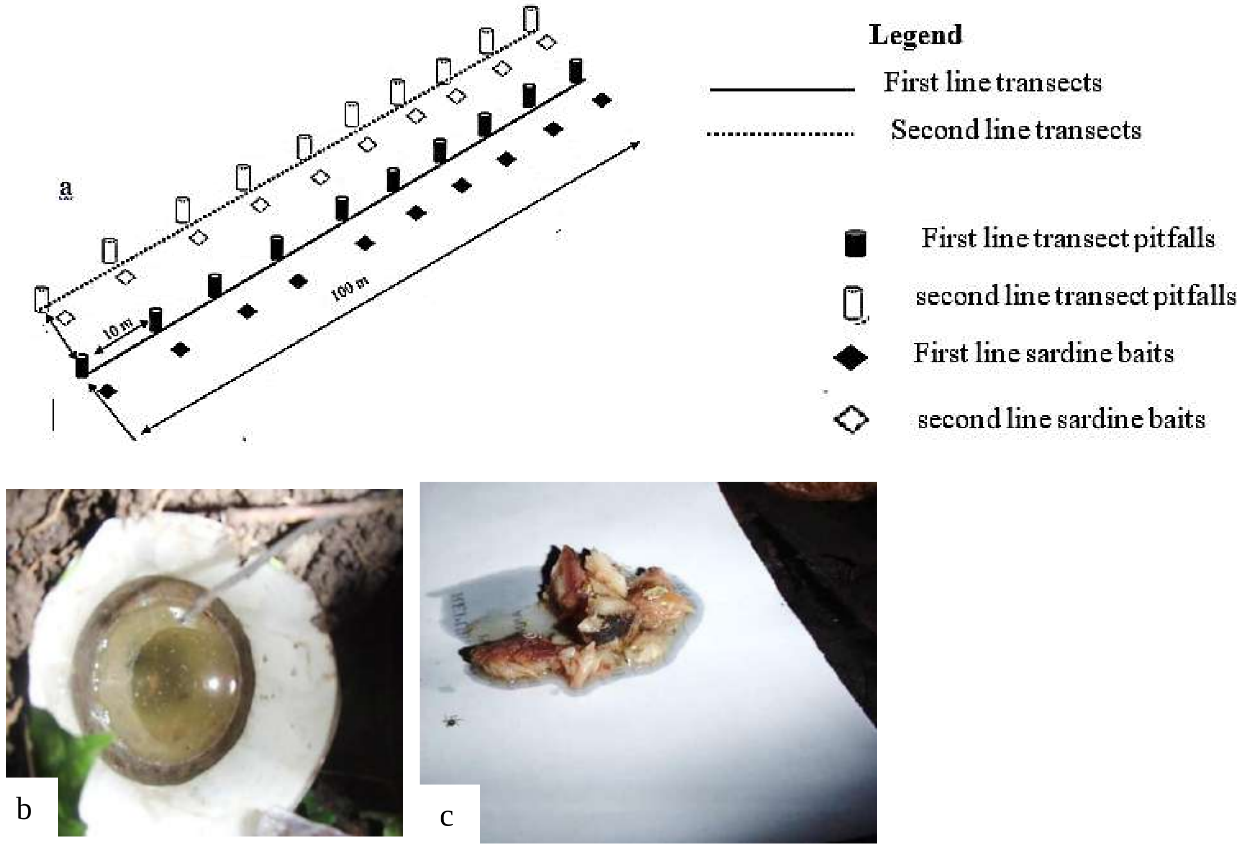


Figure 18: Experimental design of ant sampling showing (a) both pitfall and bait traps installed along line transects; (b) pitfall and (c) sardine bait traps established to sample ants (Photo GF Difouo, 2020).

II.2.2.3.2 Understory and below-ground termite communities

II.2.2.3.2.1 Hand- sampling of termites

All feeding sites that were attributed to pangolin activity on the line transect and recces were sampled (Fig. 19). Termites were sampled in major habitat types of each protected area in ground-level and understory termite feeding or nesting microhabitats (Luke *et al.*, 2014). Seven and six habitat types were targeted for termite sampling in MDNP and DDNP respectively following the protocol adopted by Abensperg-Traun (1994) and Felicitas *et al.* (2018). We focused on ground-level and understory termite feeding or nesting microhabitats (Luke *et al.*, 2014), including (1) epigeal and hypogeal tree active nests, (2) ground termite mounds, (3) leaf litter, (4) dead wood (i.e, decaying tree trunks and twigs), and (5) galleries (i.e., build with soil) on tree trunks up to a height of 2 m (Eggleton & Bignell, 1995) (Fig. 19). Termites was sampled on tree nests, termite mounds, and dead wood following the protocol adapted from Abensperg-Traun (1994) and Li *et al*. (2011). Termites were collected on leaf litter, on the surface of tree galleries, and from inside termite tree nests and mounds where a section of the nest was cut using a machete following the protocol of Felicitas *et al.* (2018).

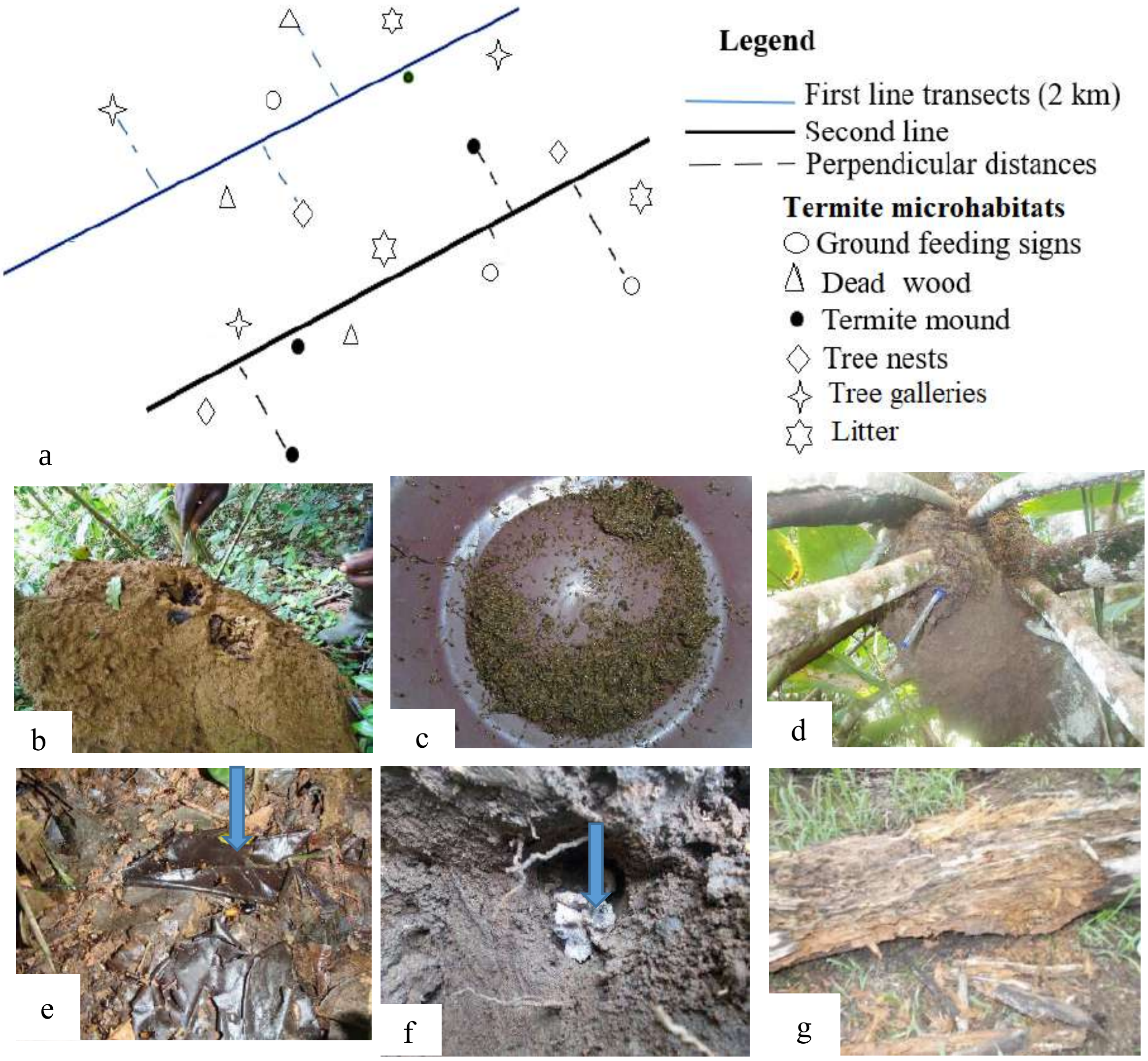


Figure 19: Survey design and different termite microhabitats sampled (a) illustration of microhabitat around line transect; (b) termite mound; (c) colony from galleries in tray; (d) tree termite's nests; (e) leaf litter, (f) subterranean termite nest from ground feeding sign and (g) dead wood (Photo GF Difouo, 2020).

II.2.2.4 Effective pangolin diet composition

II.2.2.4.1 Scat samples collection

Scat analysis is an effective and non-invasive method to determine the pangolin species' diet composition (Mahmood *et al*., 2013). During the survey period, all scat of pangolin samples encountered along the transect were collected. A single fresh scat sample (estimated to be less than 24 hours old) was collected in the Mpem et Djim grassland savanna near a living burrow. The scat was assumed to belong to an adult giant pangolin because: (1) its large dry weight (120.1 g) precludes all small-size myrmecophagous, pangolin species and juvenile giant pangolin, and the scat appeared different in shape (fusiform) and length (>8 cm) (Fig. 20a) from that described for an aardvark (*Orycteropus afer* Pallas, 1766) scat (Chame, 2003); (2) our local guides expressed confidence the scat was from giant pangolin and not an aardvark; (3) camera-trap images from the burrow captured only giant pangolins utilizing the burrow and no aardvark; and (4) the relatively close similarity of the prey species composition between the purported scat and the giant pangolin stomach content. The scat sample (n=1) was stored in fresh leaf and later transferred into a plastic Ziploc bag before analysis following previously published methods (Mahmood *et al*., 2013).

Another scat sample likely belonging to the white-bellied pangolin was collected in Deng Deng's woodland savanna. It was different from the previous collection with a smaller weight and similar prey species composition recorded for white-bellied pangolin stomach contents (Fig. 20b). An unidentified sample of scat mixed with soil and ant and termite fragments (Fig. 20c) were the most encountered.

Figure 20: Sample of pangolins' scats collected in the park habitats (a) giant pangolin in grassland savanna (MDNP), (b) white-bellied pangolin in woodland (DDNP) and (c) very old sampled of scat.

II.2.2.4.2 Stomach contents collection

There is no protocol to extract pangolin stomach content without the risk to cause individual death. The Ministry of Forestry and Wildlife provided a research permit that allowed the stomach contents of the dead pangolins to be examined. Stomach contents were collected during a community survey in the villages surrounding both DDNP and MDNP. The sampling village names are kept anonymous given the sensitive behavior regarding pangolin conservation status and their meat consumption and ethical requirements regarding the protection of respondents during questionnaire surveys (ISE, 2006). Free prior and informed consent was obtained from the village heads and villagers, and the origins and all contributors of pangolin material are anonymous. During our community survey, respondents confirmed that they have eaten pangolin meat before. We visited 100 households occasionally across 20 villages each day the early morning with a local guide. When informed if pangolin meat was about to be eaten, we collected stomach contents from the animal in the villager's possession which we stored in 90% ethanol for further analysis. A total of nine samples of WBP were collected during the dry season while four were collected during the rainy season. A single dead juvenile giant pangolin stomach content was collected. Each sample was assigned unique corresponding field numbers.

II.2.2.4.3 Pangolin scat analysis

After weighing using a digital scale (Professional Mini), the scat was soaked in fresh water and sieved with appropriate mesh, then filtrated (Fig. 21a). The scat remaining content was sorted on a Petri box for sampling insects or their body parts (heads, thorax, for example), and the early developmental stages of ants, such as eggs and pupae following protocols from Taylor *et al.* (2002). These samples were stored separately by morphospecies in 50 ml vials containing 70% ethanol for further identification.

Figure 21: Three steps in the analyzing process of scat and quantification of each content (a) scat component filtration, (b) sorting and grouping of body part fragments, and (c) scat weighing.

II.2.2.4.4 Pangolin stomach content analysis

The stomach contents of the dead pangolins (Fig. 22a) were collected during the community surveys and stored in vials containing 90% ethanol. In the laboratory, after weighing, the stomach contents were soaked in fresh water and sieved with appropriate mesh. The stomach contents were sorted on a Petri box with water to float insect parts (Fig. 22b) making them easy to collect using forceps. The contents were examined by two researchers, who identified and counted all the organic, and inorganic contents weighed separately on a scale (Lee *et al*., 2017).

II.2.2.4.4.1 Morphospecies grouping

Following the protocol adopted by Lee *et al.* (2017), large-size insects (with body length less than 7 mm; Fig. 22c) were sorted first by eye, then Petri boxes with water to float insect parts which makes them easy to collect separately using forceps. Insects were grouped into morphospecies based on external morphological characteristics of entire individuals (size, color) together with identical insect fragments, including heads and thorax that are strongly keratinized, though eggs were not considered (Fig. 22d). The number of individuals (only head) from each caste (i.e., alates, workers, and pupae) of ants and termites in each pangolin’s stomach content and scat were counted. After identification of each morphospecies stored in vials (Fig. 22e) and the small insect of less than 2 mm body length were sorted further under a stereomicroscope (Fig. 21f). Entire insect individuals and heads (for advanced prey digestion process) were used as the counting unit to prevent errors arising from repeated counting of body fragments. Figure 22 shows the process of pangolin stomach content analyzing.

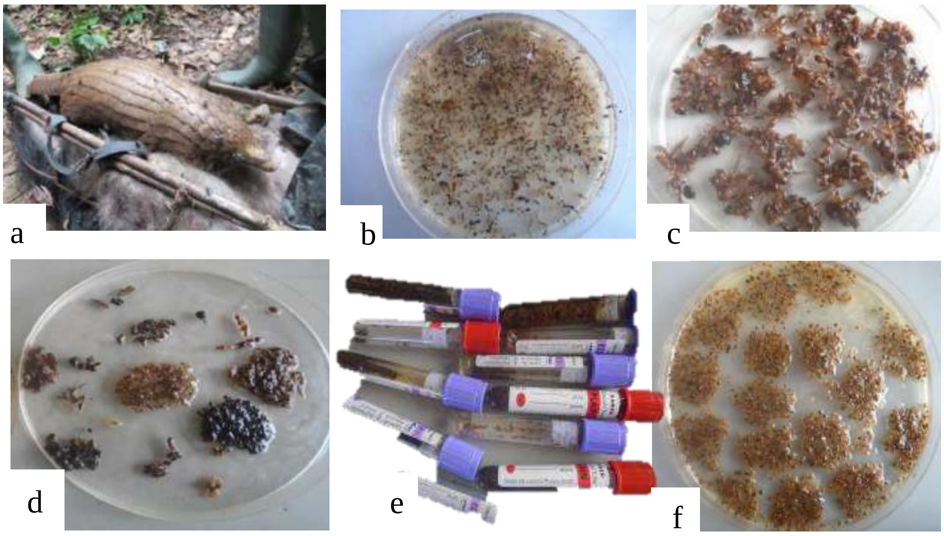


Figure 22: Analyze process of pangolin stomach contents (a) dead white-bellied pangolin from MINFOF seizure, b) portion of stomach content soaked in freshwater; c,d) a grouping of medium-size ant and termite morphospecies; (e) vials containing morphospecies preserved in alcohol for further identification; (f) small size termite species grouped to facilitate the counting number of individuals.

II.2.2.4.4.2 Species and genera identification

Identification of ant and termite specimens was made under a stereomicroscope at the magnification 20X. Morphospecies groups (unidentified ant or termite individual that differs to each other morphologically) were identified using the dichotomous keys in Hölldobler and Wilson (1990), Bolton (1994), and the African Ants systematic database (www.antbase.org). The morphometry of the head and position of the eye on the head among the ant species were used to identify them to species level based on Bolton (1994). We focused our analysis on the ant worker caste since alates are difficult to identify (Groc *et al*., 2014).

Termites were identified to genus and species levels based on soldier castes, where possible, under the morphological and morphometric characters, using appropriate dichotomous keys (Emerson *et al*., 1928; Bouillon & Mathot, 1965; Sands, 1965; Ruelle, 1970; Krishna *et al*., 2013) and Termite systematic Database (http://164.41.140.9/catal/). The main characteristics used for the distinction were the shape, size, and color of the head, the presence or absence of fontanelle, the shape of the labrum, the clypeus, the mandible, and the pronotum. The additional features of the latter were the position of the teeth on the mandibles and the number of articles of the antennas. Solderless and alates termite samples constituted at least 1% were precluded from our sampling. The morphospecies that could not be identified at the species level were given a unique name code to differentiate during counting species individuals. Voucher specimens of all the species were deposited in the fauna reference collection hall of the laboratory of zoology of Faculty of Science, University of Yaoundé 1.

II.2.3 Statistical analysis

Data were computed with MS EXCEL 2016 (Microsoft Corporation, 2018), and statistical analyses using IBM© SPSS 20 (SPSS Inc., 2011), PAST 3.0 (Hammer *et al*., 2001) EstimateS program (version 9.0) (Colwell, 2013) and R software (R Core Team, 2012).

II.2.3.1 Proportion of respondents with local ecological knowledge

Socio-economic data were analyzed using the software IBM© SPSS Statistics 20.0. Univariate analyses of frequencies were performed for qualitative non-dependent variables, including demography parameters, the number of respondents (n) who recognized each pangolin species and given their sighting locations, listed their favorite diet composition. Chi-square tests were used to compare the frequencies of responses between the age and occupation of respondents and national parks, and differences were considered significant at a 5% level of probability.

II.2.3.2 Pangolin behavior

II.2.3.2.1 Camera-trap sampling effort

Information from each image including date and time was cross-checked for the setup date (first camera operating date) and last operating date of each camera trap to evaluate its sampling effort. The sampling effort is defined by McPee (2015) as the total number of days all the camera traps installed in the survey areas were on and functional estimated between the first and last photo taken. The cumulative sampling effort of the survey period was estimated for each protected area, habitat type, season, and target (placement site).

II.2.3.2.2 Identification of pangolin from images and processing

All images or videos contained in a camera-trap station stored automatically within a Sandisck SD card (or corresponding memory card manufactured especially for the camera mark—for example, Moltrie 30i which has a Moltrie specific SD card mark) files were renamed and viewed in a laptop using Picasa software; the light was increased in some images to facilitate identification. The details (1) for animals on photo or series of photos including common and scientific names of the species, the number of animal individuals, the behavior, and the number of photos; and (2) for abiotic conditions including temperature (in degree Celsius) hours and daytime of each event were recorded. Only individuals that were visible and could be identified at the species level were recorded by the species common and scientific name; non-identifiable individuals—are those who were impossible to identify at the species level due to obscuring foliage, partial capture, etc were cataloged as NA (Non-Attributed). During this process, only photos or videos that contained a visible animal individual, identifiable or not were considered for the database. All photos or videos that contained no visible targets, due to camera misfire, individuals not being present in the field of view, or due to underexposure or overexposure of the film and false trigger were excluded from the database.

- ❖ **Independent photographic events**

Independent photographic events of pangolins were counted (Tobler *et al.*, 2008; Wearn *et al.*, 2013). Data was input into a Microsoft Excel 2016 spreadsheet which was also used to generate frequencies of independent events and radial plots for activity patterns.

II.2.3.2.3 Investigation of pangolin behavior

Pangolin behavior was investigated through observation of each species' activities on camera trap photos or/and videos using Picasa Software on a Personal Computer (PC). Two trained researchers were observers and recorders in Excel spreadsheet data. They interpreted and confirmed the observed activities. The observation started at the first sighting of the individual in the image or video and ended at either the end of the video or sequence of images or when the individual left the view of the camera.

- ❖ **Classification of different types of pangolins activity**

The observed pangolin activities which determine their behaviors were defined and categorized as follows:

✓ "**passing**": an activity that does not include direct interaction of both pangolin individuals and the targets, e.g., walking away from feeding target or passing it;

✓ "**exploration or foraging**": pangolin individual approaches the target and exhibits naso-inspection and sniffing target or not; or climbing on a termite mound. The events that generated a sequence of at least 10 consecutive photos of the same individual showing research of food or not were considered foraging activity (considering the time spent by the pangolins on the target) or evidence of a pangolin individual searching food.

✓ "**feeding/eating**": evidence of a pangolin individual on photos spending longer periods with its nose on the feeding site known to contain insect prey or evidence of feeding action on videos;

✓ "**entering or/and exiting burrow**'' pangolin observed entering the hole and/or exiting later, or individual departing from the burrow with mud covering the body;

✓ "**Scent marking**'' evidence of pangolin individual on video spread anal gland secretion near the target.

The observed activities of each individual were classified into two main categories of behavior: feeding behavior (eating foraging and passing [because pangolin prior moving from one site to another to forage]) and territorial behavior (entering and exiting the burrow and scent marking). NA (non-attributed) was attributed when the observed animal activity could not be interpreted by the two observers. The trapping rate of each activity was calculated to determine how frequently each activity was observed for each species, in each habitat type, target type, and season.

II.2.3.2.4 Pangolin trapping rate

The trapping rate (TR) referring to the frequency at which a pangolin was detected was used to estimate (1) a relative abundance index (RAI) and (2) the frequency of activity of each pangolin species in the different national parks, habitat types, target types, and per year and season. The assumption that a target species will trigger cameras in relation to their abundance and their frequency of activity was made. The trapping rate (TR) was calculated as the number of events of the species divided by the sampling effort (which is the accumulated total number of days the camera installed in all habitat types operates) multiplied by 100, using Microsoft Excel 2016 following the formula adapted from McPhee (2015):

$$\mathrm{TR} = \frac{\text{Number of events}}{\text{Sampling effort}} x100$$

II.2.3.2.5 Pangolin capture rate and capture probability

The capture rate (CR) was calculated to determine how often a given species of pangolin is recorded about all other mammal species independently of the total survey length in camera trap days (McPhee, 2015). This allows us to look how commonly a species is captured inside the study area, and it was useful in ranking species by number of events. The capture rate was calculated as the total number of events of a particular species divided by the total number of all species events, multiplied by 100 following the formula adapted from McPhee (2015).

$$\mathrm{CR} = \frac{\text{Number of events of species "i"}}{\text{Total number of all species events}} x\ 100$$

This should not be confused with capture probability.

Capture probability (CP) was obtained by dividing the total number of events of each species by the total number of camera trap days in the survey. It provides the average frequency that a particular species could be recorded on any given day during the survey period given as 1/CP (McPhee, 2015). It was computed following the formula adapted from McPhee (2015):

$$\mathrm{CP} = \frac{\text{Number of events of species}}{\text{Sampling effort}}$$

The R version 4.1.2 was used to test statistically the difference between trapping rates using the Chi-square test.

II.2.3.2.6 Pangolin activity patterns

Total duration or period, specific peaks time, and the number of events of the behavioral categorized activities were measured and used to plot activity patterns as the cumulated number of events of each pangolin species activity category for all surveyed sites and habitat types. Activities from many giant pangolin (GP) individuals from both parks recorded at different camera stations were pooled to have sufficient data for radial plot. Activity pattern was plotted using Microsoft Excel 2016.

II.2.3.2.7 Habitat use and factors influencing pangolin activities

❖ Correspondence analysis

Correspondence Analysis (CA) is an extension of the principal component analysis suited to analyze a large contingency table formed by two qualitative variables or categorical data (Abdi & Williams, 2010). To test the association between pangolin activity, their habitat, and the placement target types, a correspondence analysis was undertaken using the R packages *FactoMineR* and *factoextra* (Lê *et al*., 2008). This approach generates a contingency table, where we aimed to know whether certain row elements (such as pangolin activity types) are associated with some elements of column elements (habitat types and placement target types). It provides a solution for summarizing and visualizing in two-dimension plots data set of the main pangolin activities such as “passing”, “exploration” or “foraging” and “feeding/eating” and the various habitat types and the type of target where the camera traps were placed. Correspondence Analysis (CA) was used to analyze frequencies formed by two categorical data in a contingency table. CA contains three basic concepts: (1) that of a point in multidimensional space, (2) a weight (or mass) assigned to each point and, (3) finally, a distance function between the points, called the chi-square distance. It provides factor scores (coordinates) for both row and column points of a contingency table. These coordinates helped to visualize graphically the association between row and column elements in the contingency table. The chi-square test of independence was generated to evaluate whether there is a significant association between pangolin type of activity and either habitat types or placement target types. *FactoMineR* package was used to predict the coordinates of variables and supplementary individuals using the information provided. The R package *factoextra* was used to extract quickly, in a human-readable standard data format, the analysis results from the different packages mentioned above. It produces a *ggplot2* (Package)-based elegant data visualization with less typing. The association between ant species and habitat type was tested using a correspondence analysis undertaken employing the R packages *FactoMineR* and *factoextra* (Lê *et al*., 2008).

❖ Generalized linear models

The following parameters: season, placement target types, year, and the different pangolin activity types (behavior) were incorporated into a series of generalized linear models (GLMs) to assess their individual or combined influence on the trapping rate of giant pangolin and white-bellied pangolin species. The best-performing model is the one with the smallest Akaike's Information Criterion (AIC; Mazerolle, 2004). The R package *dispmod* performs analysis via the function *glm* and automatically computes the Pearson Chi-square p-values to evaluate if the association is significant or if the factors significantly affect the pangolin trapping rate. All analyses were performed employing the software R v. 4.0.3 (R Core Team, 2020)

II.2.3.3 Insect community assemblages

II.2.3.3.1 Species richness estimation indices

- **Species richness and species percentages**

Species richness « S » refers to the number of species present in an ecosystem (Peet, 1974). The number of potential insect prey species were assessed in habitat types and parks, and the actual prey species in different pangolin meals were recorded. Percentage of species were calculated as the number of species (e.g., in subfamily, park and habitat or pangolin stomach) divided by the total number of species identified multiplied by 100. Comparisons of species percentages among habitat types, parks, seasons, and among pangolin individuals were carried out using a Chi-square test in R version 4.0.2 (R Core Team, 2020).

- **Sampling success**

To evaluate the strength of the sampling success (SS), the theoretical species richness (TSR) was calculated using nonparametric estimators. The EstimateS software (version 9.0) automatically generates the values of eight estimated and we selected four incidence-based indices using presence/absence data. The sampling success (SS) was expressed as the ratio

$$SS = (S._{obs}/TSR) \times 100$$

where $S._{obs}$ is the observed species richness and TSR the theoretical species richness (Magurran & McGill, 2011). TSR was estimated using the means of four nonparametric incidence-based estimators: the first and second order Jackknife (Jack1 and Jack2), second order Chao (Chao2) and ICE (Incidence based Cover Estimator; Magurran & McGill, 2011) employing EstimateS software (version 9.0). An average from the values of the indices was determined. The observed specific richness was then divided by the average value obtained to know the sampling efficiency (Magurran & McGill, 2011). The formulas of the different estimators of TSR are as follows:

- ✓ **Jackknife 1 or S_{jack1} and Jackknife 2 or S_{jack2}**

$$\mathrm{S_{jack1}} = \mathrm{S_{obs}} + \mathrm{Q_1}\left(\frac{\mathrm{m}-1}{\mathrm{m}}\right) \qquad \mathrm{S_{jack2}} = \mathrm{S_{obs}} + \left[\frac{\mathrm{Q_1}(2\mathrm{m}-3)}{\mathrm{m}} - \frac{\mathrm{Q_2}(\mathrm{m}-2)^2}{\mathrm{m}(\mathrm{m}-1)}\right]$$

Where $S_{Jack1\ \&\ 2}$: theoretical specific richness;
S_{obs}: observed specific richness;
Q_1: number of unique species in a sample;
m: number of samples taken on the site.

- ✓ **Estimation Index Chao 2 (S_2)**

$$\mathrm{S_2} = \mathrm{S_{obs}} + \frac{\mathrm{Q_1^2}}{2\mathrm{Q_2}}$$

Where S_{Chao2}: Estimated specific richness;
S_{obs}: Specific richness observed;
Q_1: Number of unique species in a sample;
Q_2: Number of species common to the different batches sampled.

- ✓ **ICE estimate index (Incidence based Cover Estimator)**

$$\mathrm{ICE} = \mathrm{S_{freq}} + \frac{\mathrm{S_{infr}}}{\mathrm{C_{ice}}} + \frac{\mathrm{q_1}}{\mathrm{C_{ice}}}\gamma^2_{\mathrm{ice}} \text{ où } \gamma^2_{ICE} = max\left[\frac{S_{infr}}{C_{ice}}\frac{m_{infr}}{(m_{infr}-1)}\frac{\sum_{k=1}^{10} k(k-1)q_k}{(n_{infr})^2} - 1{,}0\right]$$

S_{infr}: number of infrequent species (sought in samples of size ≤ 10);
S_{freq}: number of common species (sought in samples of size ≤ 10);
m_{infr}: number of samples that has or less one infrequent species;
N_{infr}: total number of occurrences of infrequent species;
q_1: number of unique species;
q_i: number of species found in sample i;
C_{ice}: 1-q_1 / N_{infr}

- **the sample rarefaction or Mao's tau curve**

Species richness determination is an important aspect of the studies of the diversity of populations. It assesses the efficiency with which a given environment has been sampled. Sampling success is usually obtained by plotting accumulation curves of species (cumulative number of species or S observed depending on the number of occurrences [presence/absence] of each species). These curves were built using the PAST software and rearranged using Excel 2016. The program computed these curves at a 95% confidence interval using the analytical formulas (Colwell *et al.*, 2004). Knowing that the shape of these curves is influenced by the order in which each sample is added to the total (Colwell, 2013; Longino, 2000), the order of the samples was randomly drawn 100 times with the EstimateS program to produce smooth and even curves (Colwell, 2013; Longino, 2000). Sampling is deemed to be relatively comprehensive when the species rarefaction curve begins to plateau. However, in some tropical species, there may be a large number of rare species, especially among insect and plant taxa (Gotelli *et al.*, 2011). The expected specific richness was used to plot the sample rarefaction curve or Mao's tau curve of ant and termite potential preys in habitat types. Such curves indicate the cumulative number of new species found when a community is sampled randomly. They estimate the number of species expected for a certain number of samples (Magurran & McGill, 2011).

II.2.3.3.2 Diversity of potential insect preys

II.2.3.3.2.1 Diversity of potential ant and termite preys

- **Diversity indices**

The diversity is the measure of richness and the relative dominance of different species. A community of ten species, each with 100 individuals, has a high diversity, whereas if one species has 100 individuals and the rest 10 each, then the diversity measure is lower (Magurran & McGill, 2011). The diversity of ant communities within and between seasons in each protected area and habitat type was characterized and compared. The assemblage of samples was evaluated using several diversity indices: Shannon–Wiener diversity index (H’), Evenness (J), and Berger-Parker's Specific Dominance Index (ID). The means of indices were calculated per pitfall trap and tested using either Kruskall-Wallis (H) for habitat types or the Wilcoxon-Mann-Whitney test (Mann-Whitney U) for the national park because data were not normally distributed.

The dominance of ant species in the different communities was assessed using Berger-Parker's Specific Dominance Index (ID; Magurran & McGill, 2011). The variation in the mean Shannon index and the average fairness between the different levels (national parks, habitat types, and seasons) was tested either using the Kruskall-Wallis (H) test associated with Mann-Whitney pairwise comparison test when the distribution was not normal. Comparisons of the diversity indices between national parks were made using Wilcoxon-Mann-Whitney because data were not normally distributed. Normality was tested using the Shapiro-Wilk test and homoscedastic using Levenne's F texts. The results were assessed at the 5% threshold and analyses were carried out using the software PAST version 3.20 (Hammer *et al.*, 2001).

- ✓ **Shannon-Weaver diversity index (H’)** (Shannon, 1948; Shannon & Weaver, 1949)

Shannon-Weaver diversity index « H’» measures the sum of uncertainty degree to predict the probability of one individual selected randomly in the sample to belong to the S species bundle and N individual **(**Washington, 1984). The index is given by the following relation:

$$H' = -\sum_{i=1}^{S^*} (p_i * \mathrm{Log}_2\, p_i) \quad \text{with} \quad pi = \frac{ni}{N}$$

Where P_i= proportion of the individual of the species « i » of the study area;

S= total number of species of the study area;

$n_{i=}$ number of individuals of the species « i » and

N= total number of individuals in the sample.

H' fluctuates between 0≤ H'≤ ln(S) which is H_{max}: H' = 0 if the community is constituted by one species only (lower diversity); H'≤ H_{max} for a maximal value if all the species have the same number of individuals (highly diverse communities).

- ✓ **Evenness index of Piélou (E)**

$E = H'/H_{max}$

Where H 'is the Shannon diversity index; H_{max} (maximum diversity) = ln(S) of a stand of the same species richness.

The Piélou Equitability index varies between 0 and 1. It will tend towards 0 when in the community almost all the abundances are concentrated on a single species and towards 1 when most of the insect species in the community have almost the same abundance (Magurran & McGill, 2011).

- ✓ **Dominance Index of Berger-parker (ID)**

It is the ratio of the relative abundance of the dominant species (n_{max}), to the abundance of all the species in the surveyed area (N). It is given by the following formula:

$$ID_{\text{Berger-Parker}} = \frac{\mathrm{n_{max}}}{\mathrm{N}},$$

with 0<ID<1; ID = 0 indicates an absence of dominance where all taxa are present in equal abundance; ID = 1 denotes that one or a few taxa are numerically the most abundant in the community (Magurran & McGill, 2011).

II.2.3.3.2.2 Community similarity

The differences between two community (beta diversity) were assessed employing (1) Bray-Curtis dissimilarity index and (2) cluster dendrogram. Cluster dendrogram with AU p-value was preferred to Bray-Curtis distance.

- ❖ **Bray-Curtis dissimilarity index**

The analysis was carried out using EstimateS program to generate index values (Colwell, 2013). The Bray-Curtis index (BC) is given by the formula:

$$Bc = 1 - \mathrm{Cn} \text{ with } Cn = \frac{\mathrm{2JN}}{\mathrm{Na+Nb}}$$

Na + Nb with Na: total number of individuals from site A;

Nb: total number of individuals from sites B; and

JN: sum of the abundances of the species found in the two parks.

Note that if JN = 0 then. Cn = 0 indicates a total dissimilarity between the different communities. Cn, tend towards 1 for the more similar communities.

- **Cluster Dendrogram**

Clustering is the grouping of data objects into discrete similarity categories according to a defined similarity or dissimilarity measure (Suzuki & Shimodaira, 2006). Dendrograms were plotted to show the relationship between similar ant communities across different habitat types and pangolin individual meals employing the R package *pvclust* (Suzuki &.Shimodaira, 2006). To do this, an abundance matrix with species in rows and habitat types or pangolin individuals in columns was constructed. The matrix was then Hellinger transformed using the *decostand* function from the 'vegan' package (Oksanen *et al*., 2018). It permits to obtain normality and adjust variance prior to multivariate analysis. The Hellinger transformation has good statistical properties to test for relationships among explanatory variables and draw biplots in constrained or unconstrained multivariate ordination without resorting to the Euclidean distances (Legendre & Gallagher, 2001) and is also suited to data sets with multiple zero values. The distances between groups or classes were calculated using the Euclidean method employing the *dist*() function. *pvclust* performs hierarchical cluster analysis via the function *hclust* and automatically computes p-values for all clusters contained in the clustering of original data. It also provides graphical tools such as *plot* function or useful *pvrect* function which highlights clusters with relatively high/low p-values. It is also used to assess the uncertainty in hierarchical cluster analysis (Suzuki & Shimodaira, 2006). In fact, for each cluster in hierarchical clustering, quantities called p-values were calculated via multiscale bootstrap resampling. The p-value of a cluster is a value between 0 and 1, which indicates how strong the cluster is supported by data. *pvclust* provides two types of p-values: AU (Approximately Unbiased) p-value and BP (Bootstrap Probability) value. AU p-value, which is computed by multiscale bootstrap resampling, is a better approximation to unbiased p-value than the BP value computed by normal bootstrap resampling and determine the robustness of a cluster. For AU p-value ≥ 95, the node was considered highly significant and for AU p-value ≥ 90, the node was considered weakly significant. Dendrograms were also used to assess the similarity of termite and ant prey's specific composition and the similarity of pangolin prey and habitat insect communities. We assessed which pangolin meal was more similar to each other and the ant community of the surveyed habitats.

II.2.3.3.3 Frequency of occurrence of potential and actual preys

II.2.3.3.3.1 Frequency of occurrence of potential preys

The frequency of occurrence (F_o) of each potential prey across protected areas, habitat types, and seasons was computed. We also computed the frequency of occurrence of actual preys in different stomach contents (for white-bellied pangolin only) because a single sample of stomach and scat of giant pangolin was obtained:

$$\% F_o = (f_i/F_{t)}) \times 100$$

where f_i = occurrence of each insect's species "i" in the sampling units;

F_t = total number of sampling units (termite micro-habitats; pitfalls) examined or total number of pangolin individuals examined.

To characterize the frequency of occurrence (F_o) of pangolin potential preys in habitat type, park and season, we grouped the frequency of occurrence of each species into four categories following Dajoz (1982):

- if $F_o > 50\%$ the species is considered to be constant or common (meaning the species is consistently recurring over time or space) in the community;
- if $25\% \leq F_o \leq 50\%$ the species is considered to be accessory or less common (the species is present in a minor amount, not essential) in the community;
- if $F_o < 25\%$, the species is considered to be rare/accidental or uncommon (opportunistically recorded) in the community;
- if $F_0 = 0\%$, the species is absent in the community.

II.2.3.3.3.2 Abundance mean of potential and actual preys

The abundance mean was calculated as the mean number of individuals of all species per pitfall trap or in four pangolin individual stomachs recorded, for each habitat type, each park, and season. As our samples include a low number of Dorylinae, the abundance calculation for ant was used, but termite relative and mean abundance were not estimated as the sampling methods employed were not useful for this measure for this particular social insect group (Eggleton & Bignell, 1995).

- Various mean of variables and standard deviation (ants only) were computed in habitat type and parks and the stomach contents (ant and termite) were examined;
- Means were compared using the Kruskal-Wallis test (H) for several samples adjusted by the Bonferroni test for comparison of more than four samples and difference significant if p-value <0.003 and Wilcoxon-Man-Whitney (U) test for two samples. The Mann-Whitney test was used for pairwise comparisons when there was a significant difference. Comparisons were not made between national parks because a majority of most of the stomach contents sampled came from outside of one park.
- The Shapiro-Wilks test was computed to assess normality our samples employing PAST 3.0 with a p-value equal to 0.05.

II.2.3.4 Relative importance of actual preys

Relative importance (RI) of prey species was computed and classified to evaluate each prey species importance in pangolin diet composition (Albarracin *et al.*, 2009), using the terminology from (Geistdoerfer, 1975). RI was calculated as the relative abundance of each species multiplied by its frequency of occurrence Albarracin *et al*. (2009). It was used because it considers both the number of times a species was sampled and the abundance (estimated total number of individuals) of this species.

II.2.3.4.1 Relative abundance

Relative abundance is the percentage of individuals of a species “i” taken about the total of individuals of all species combined. The relative abundance (A_r) of each insect’s actual prey species (ants and termites) was computed in different stomachs examined, for each season using the following expression:

$$A_r = (n_i/N) \times 100$$

where, n_i = absolute abundance of each insect’s species, and N = total number of insect individuals in all stomachs.

II.2.3.4.2 Relative importance of prey species

The Relative Importance (RI) was not computed for the giant pangolin diet as we have only one stomach and scat sample. RI was computed as follows:

$$RI = A_i \times F_o$$

where A_i = relative abundance of the species “i” observed in a stomach content and

F_o = frequency of occurrence of species “i” in all pangolins examined.

$$F_o = (f_i / F_t) \times 100$$

where f_i = occurrence of each insect’s species “i” in all pangolin individuals (number of times a species “i” is recorded in all sampled animals divided by total pangolin sampled)

F_t = total number of pangolins examined.

RI value ranges from 0 with no upper bound. The prey species were grouped into three categories according to the classification adapted from Geistdoerfer (1975) and Albarracin *et al*. (2009):

- for RI>0.5 the species was considered frequent in diet being the main prey species or preferentially consumed;
- for 0.1<RI≤0.5 the species was considered scarce in diet or secondarily consumed prey species;
- RI≤0.1 the species was considered accidental in diet or rarely eaten prey species.

II.2.3.4.3 Habitat and prey selectivity

Most commonly, selection studies deal with food or habitat selection. Food selection may be among various prey species or among the same species’ sizes, colors, shapes, components.

Habitat selection may be among various discrete habitat categories (e.g., open field, forest) or among a continuous array of habitat attributes such as shrub density, percentage cover, distance to water, canopy height, etc (Manly *et al*., 2002). Habitat selection has been studied in the field by measuring the amount of time spent by individuals in each of the available habitats (Durbin, 1998) or through a count of the number of seasons a plot is used. For example, the proportion of radio locations in each habitat type was then compared to the relative availability of the respective habitat type in the study area. In this study, resources include insect prey eaten and habitats used by pangolin species. Manly's standardized selection index for common resources was used to evaluate resource preference for each pangolin species. This index does not fluctuate with the inclusion or exclusion of seldom-used (rarely or commonly used) resources (Manly *et al*., 2002) and is considered more versatile (easily adjustable) than other selection indexes (Garshelis, 2000). It is based on the selection ratio W_i.

- **Selection ratio**

The selection ratio is the proportional resource item use divided by the proportional availability of this resource item (Manly *et al*., 2002). It gives the resource selection function meaning the relative probability of selection for category i. Previous authors have consecutively called the selection ratio, selectivity indices (Manly *et al*., 1972), and preference indices (Hobbs & Bowden, 1982). Many factors contribute to resource selection (Peek, 1986). These factors include population density, competition with other species, natural selection, the chemical composition or texture of forage, heredity, predation, habitat patch size and inter-patch distances (Manly *et al*., 2002). Selection ratio should not be confused with preference although selection and preference are often used as synonyms in the literature (Manly *et al*., 2002).

The selection ratio was computed as the proportional prey or habitat item used divided by the proportional availability of the same prey or habitat item (here the proportion of insect prey sampled is considered as the proportion available (Manly *et al*., 2002). Selection ratio of habitat by pangolin was determined by the species trapping rate in a habitat divided by the frequency of habitat in park. And forage ratio of ant and termite species were determined by the frequency of each species recorded in pangolin meals divided by the frequency of the species sampled in the habitat. This selection ratio gives the resource selection function (the relative probability of selection for category i). The selectivity of each prey for both ants and termites or of each habitat type for pangolin species was evaluated by the equation of Manly *et al.* (2002) with a formula.

$$\dot{W}i = \frac{Oi}{\pi i}$$

With O_i, the proportion of prey type 'i' observed in 'i' pangolin diet, and π_i the proportion of prey type 'i' that is available (sampled) in its habitat. For habitat type O_i is the trapping rate of pangolin species 'i' recorded in habitat type 'i' and π_i the percentage of the habitat 'i' that is available. The forage ratio ranges from 0 to infinity. A Wi value larger than 1 indicates a positive selection for the resource and value less than 1 indicates avoidance of the resource. A value around 1 indicates that the resource was used proportionally to its availability and no resource selection was noted.

- **Preference**

In theory, components can be ranked from "most preferred" to "least preferred." Preference was ordinarily claimed to be independent of availability, but is generally defined by reference to the choice made at equal availabilities (Morrison & Mathewson, 2015). In this study, the preference/avoidance of the white-bellied and giant pangolins for each resource (prey and habitat type) was calculated from the selection ratio W_i and tested for each prey species using a chi-square test adjusted by Bonferroni procedure. Selection ratios were standardized so that they add to 1 using Manly's standardized selection ratio to compare white-bellied pangolin prey and habitat selection following the equation:

$$Bi = \frac{Wi}{\sum_{i=1}^{n} Wi}$$

Where: n = the number of resource units.

$Bi \geq 0.5$ denotes the highest probability of prey to be selected among many available, $0.5 \leq Bi \geq 0.1$ denotes higher probability of prey to be selected and lower probability of prey to be selected when $Bi \leq 0.1$.

Bi values enable direct comparison between selection ratios within each resource unit (habitat or insect prey) and can be interpreted as the probability that for any selection event, an animal would choose the category 'i' resource unit over 'n' others, assuming that all resource units are available to the animal in equal proportion (Manly *et al.*, 2002). The percentage of each habitat type 'i' available in the entire study area and the trapping rate of pangolin 'i' in the same habitat type was used to calculate Manly's selectivity index (Bi) for habitat use. This conceals variations in habitat selectivity between landscapes but facilitates comparisons of habitat selection between species. Habitats or insects' preys with the highest Manly's selectivity index (Bi) were considered key habitats or preys for the pangolin species. Insect prey of the communities and habitats that were positively selected by pangolins are considered key prey or habitat for that pangolin species. Calculations were made with Microsoft Excel 2016.

Chapter III:

Results and discussion

III.1 Results

III.1.1 Perception of local people about pangolin

III.1.1.1 Demographic of respondents

A total of 376 respondents were interviewed across 20 villages surrounding Mpem et Djim and Deng-Deng National Parks. Not all respondents answered all questions, so the total number of respondents (N) differs between questions. The interviewees belong to 42 indigenous and non-indigenous ethnics among which the "*képéré"* was the most representative (23.5%, n=96; see Fig. 23). The majority ethnic groups include: *Baboutė* (18,5%, n=68), *Vouté* (9.5%, n=35), *Pôl* (4.6, n=17), *Tikar* (3.3%, n=12) *Boblis* (2.7%, n=10), *Mbaki* (2.2%, n=8), *Etôn* (1.1%, n=4) and other minority of less than 1% *Betsi* (n=2), *Bassa* (n=2), *Nanga* (n=1), *Pèré* (n=2), *Faly* (n=1), *Masa'a* (n=1), *Guidar* (n=3), *Moudan* (n=1), *Kako* (n=3), *Maka* (n=3), *Mbom* (n=2), *Mbetem* (n=4*), Etinga* (n=2), *Mbimo* (n=1), *Manguissa* (n=1), *Bafia* (n=1), *Sanaga* (n=3), *Ngoundal* (n=1), *Sah ghari* (n=1), *Nyamsong* (n=2), *Biachota* (n=3), *Baveck* (n=1), *Nyang-ba* (n=1), *Sanbongaré* (n=1), *Ndjanti* (n=2), *Bamvélé* (n=2), *Ewondo (n=*3*)* and non-indigenous ethnic groups, such as *Foulbé* (n=3), *Toupouri* (n=1), *Wimboum* (n=2*),Bamiliké* (n=3*)*, and *Bulu* (n=2).

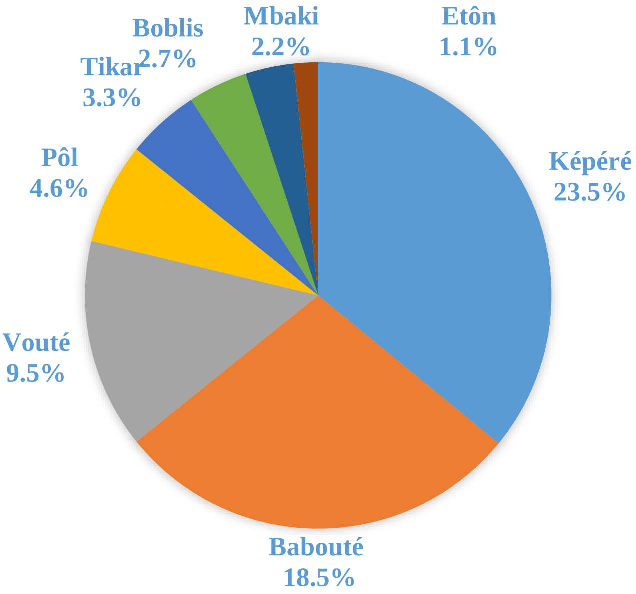


Figure 23: Primary ethnic groups in the surveyed areas.

Men were interviewed more (82.1%, n=308) than women (17.9%, n=67). The interviewees were almost all Christian (85.0%, n=317) with a minority of Muslim (13.9%, n=52). They were mostly young people with the majority aged between 15-45 years old (65.3%, n=246).

The main occupations of the respondents were farmer (68.9%, n=257), fisher (9.1%, n=34), trader (8.8%, n=33), and hunter (8.0%, n=30; Fig. 24). The other villagers' occupations include secondary students (8.8%, n=33), wood activities sector (4.6%, n=17), drivers (2.9%, n=11), housewife (2.4%, n=9), teachers (1.1%, n=4), village heads (2.1%, n=8), technicians (2.4%, n=9), and other occupations representing <1%), guardian (n=1), secretary (n=2), Pastor (n=3), high school student (n=1), mason (n=1), call boxer (n=1), livestock (n=2) and unemployed (2.1%, n=8; see Fig. 24).

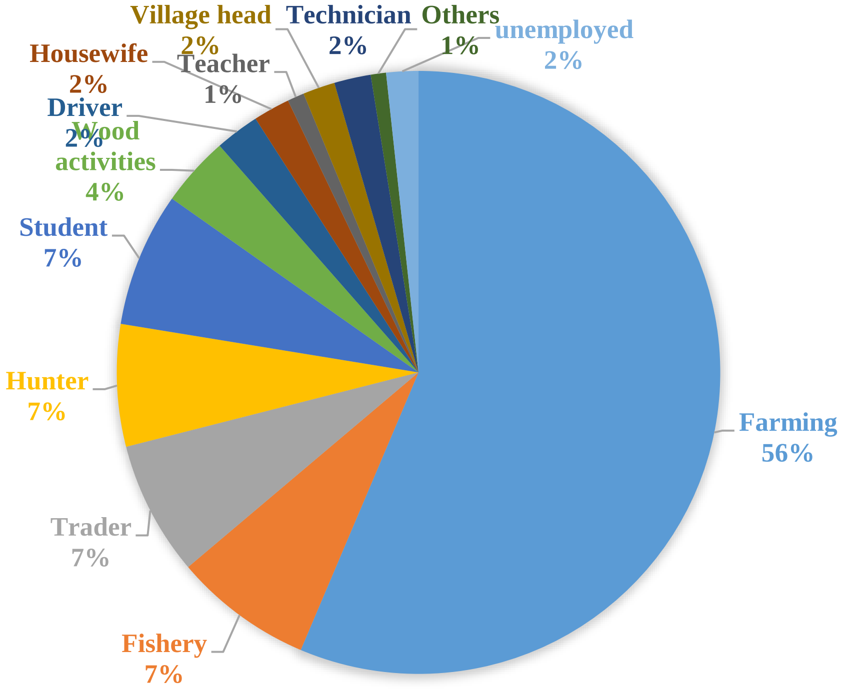


Figure 24: Main occupation of respondents in the surveyed areas.

III.1.1.2 Identification of pangolin presence in the surveyed areas

Local name of pangolins

The local names for pangolins varied among the ethnic groups of the villages located around the two protected areas (see Table III). The giant pangolin was named *Ngouroumuotou* in képéré, *Ivim* in Boblis, *Kakambia* in Gbaya, *Phimo* in Pôl and Mbaki then *Bouya* in Kako. The White-bellied pangolin was locally called *Ngaga* in Vouté/Bablouté *Kéyé* in képéré, *Kâ* in Boblis, *Sèwè/ Sèvè/ Kèkèyèkè* in Gbaya, *Sali* in Pôl, *Gâ* in Mbaki and *Ngao* in kako. The Black-bellied pangolin was poorly known and it has not been named locally.

Table III: Reported names of different pangolin species by ethnic groups located in the Centre and East regions of Cameroon.

Ethnic groups	Giant pangolin	White-bellied pangolin	Black-bellied pangolin
Képéré	*Ngouroumoutou*	*Kéyé*	-
Boblis	*Ivim*	*Kâ*	-
Gbaya	*Kakambia*	*Sèwè/Sèvè/ Kèkèyèkè*	-
Pôl	*Phimo*	*Sali*	-
Mbaki	*Phimo*	*Gâ*	-
Babouté/Vouté	*Ngouroumoutou*	*Nga-Nga*	*Koyo*
Kako	*Bouya*	*Ngao*	-

Pangolin identification

Giant pangolin

Of the respondents, 95.4% (n=351) recognized the giant pangolin and correctly named the species in French (*pangolin géant*) or the equivalent in their native languages (see Table III above). Among them, 92.4% (n=350) had already seen this species (Fig. 25). People aged between 25 to 35 years old recognized the giant pangolin most frequently (χ^2=[X=4, N=359] =11.35, p=0.02) as compared to other age class group.

White-bellied and Black-bellied pangolins

Almost all respondents (96.7%, n=356) recognized the white-bellied pangolin (92.4%, n=340; Fig. 25) and named it in French (petit pangolin) or their native language. Of those who recognized the white-bellied pangolin, 92.7% (n=341) admitted to having seen this species (Fig. 25). Only 39.9% (n=147) of interviewees were able to recognize and distinguish morphologically the black-bellied from the white-bellied pangolin but did not name them differently in French. For the black-bellied pangolin, respondents (27.2%, n= 100) reported the name petit pangolin, the same as for the white-bellied pangolin, and only one respondent reported a local name of *koyo* (Table III). Just 23.6% (n= 87) said they had seen the black-bellied pangolin (Fig. 25). People aged between 45 to 55 years old were significantly able to name the black-bellied pangolin in French (χ^2 [X= 4, N=184] =16.46, p= 0.03), and was the age group to have most frequently seen this species (χ^2 [X = 4, N = 319] =15.07, p=0.005) as compared to other age groups.

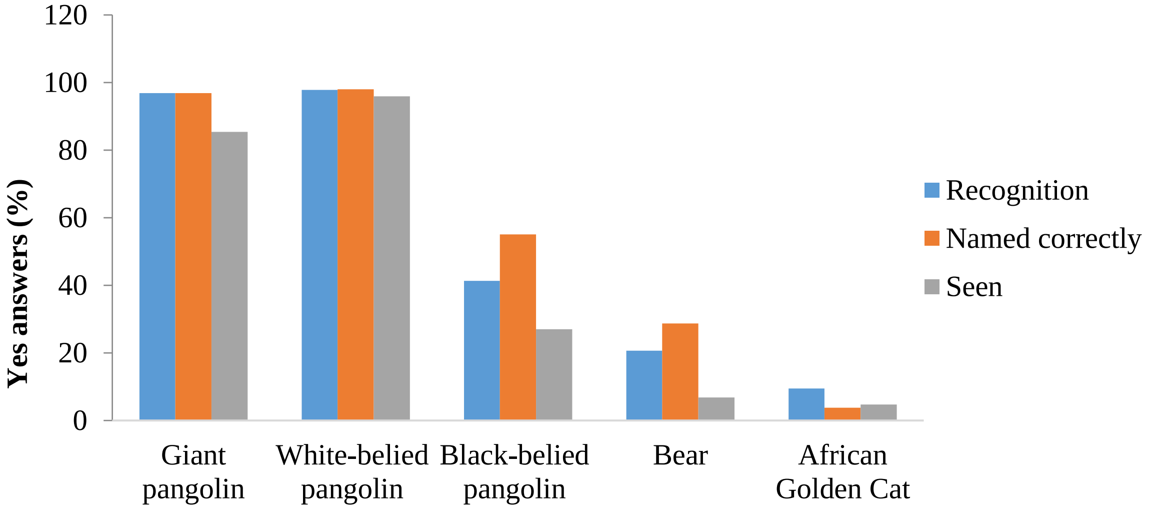


Figure 25: Identification of the pangolin species and control species from recognition, properly named and seen

III.1.1.3 Pangolin sighting locations

Giant pangolin

Respondents reported seeing giant pangolins (GP) most frequently in the forest (40.2%, n =148), but also alive or dead in villages (including wild and/or captive; 27.2%; n=100), in savanna areas (23.3%, n =99), and in local markets (20.9%, n=77) (Table IV). In savanna habitat, giant pangolins were reportedly encountered at burrows (33.7%, n= 29), on the ground (24.1%, n=26), on termite mounds (22.1%, n=19) and ants’ nests (15.1%, n= 13), and sometimes near swamp areas (11.6%, n=10; Table IV). In the forest, giant pangolin was frequently sighted in burrows (19.7%, n= 14), on termite mounds (17.1%, n=13), in swamp forest (17.1%, n=13), and on the ground (15.5%, n=11; Table IV).

White-bellied pangolin

The white-bellied pangolin (hereby WBP) was most frequently sighted in forest habitats (51.9, n= 190), in villages (36.7%, n= 135) and markets (27.7%, n=102), and in savanna habitats (23.09%, n= 85) (Table IV). Respondents who were farmers reported seeing the white-bellied pangolin in forests significantly more than in other locations (χ^2 [X=4, N=200] =4.67, p =0.03). In savanna habitat, this species was reported to be found predominantly near farms (5.6%, n=20), but also on the ground (5.3%, n= 19), on trees (5.1%, n=18), and on human paths. While in forest habitat, the white-bellied pangolins were reported in a wide range of locations, but predominantly on trees (35.2 %, n= 81), fallen logs (34.5%, n=80), on human paths (20.1%, n=74), and on the ground (15.7%, n=33; Table IV).

Black-bellied pangolin

The black-bellied pangolin (hereby BBP) was reported to be found most often in forest habitats (12.8%, n= 47) and in villages (5.9%, n= 22), and rarely in savannas (2.9%, n=10) and markets (1.9%, n=7) (Table IV). Black-bellied pangolin was frequently reported to be found on palm trees and in swamp areas in both the savanna and forest habitats.

Table IV: Percentage of respondents who reported seeing each species of pangolin in different broad location categories, and in more specific locations within forest and savanna habitats. Respondents were able to provide more than one suggestion.

Sighting locations		**Relative frequency (n)**		
		GP	**WBP**	**BBP**
Samples size	→	**N=368**	**N=368**	**N=368**
Main sighting places	Forest	40.2 (148)	51.6 (190)	12.8 (47)
	Savanna	26.9 (99)	23.09 (85)	2.7 (10)
	Market	20.9 (77)	27.7 (102)	1.9 (7)
	Village	27.2 (100)	36.7 (135)	5.9 (22)
	Specific locations	**GP**	**WBP**	**BBP**
In savanna	Human track	0	1.6 (6)	3.4 (3)
	Near farms	1.63 (6)	5.6 (20)	4.5 (4)
	Ant’s nests	15.1 (13)	0	0
	Termite’s mounds	**22.1 (19)**	**3.3 (11)**	0
	Trees	0	5.1 (18)	0
	Lianas	0	0	0
	Rattans	0	0	2.6 (2)
	Logs	0	3.5 (8)	0
	Burrows	**33.7 (29)**	**0**	0

	Swamp areas	11.6 (10)	0.8 (3)	11.6 (9)
	Ground	24.1 (26)	12.3 (19)	0
In forest	Human track	0	20.1 (74)	0
	Near farms	0	14.4 (53)	0
	Ant's nests	6.08 (9)	0	0
	Termite's mounds	17.1 (13)	6.1 (13)	0
	Trees	**9.46 (14)**	**35.2 (81)**	0
	Lianas	0	1.3 (3)	0
	Rattans	0	2.6 (6)	5.2 (7)
	Logs	**2.70 (4)**	**34.5 (80)**	0
	Burrows	19.7 (14)	0	0
	Swamp areas	17.1 (13)	10.5 (21)	3.2 (5)
	Ground	15.5 (11)	15.7 (33)	0

Not all respondents answered all questions, so the total number of respondents (N) differs between questions and total percentages can be more than 100. (n) indicates the number of respondents; GP= giant pangolin; WBP= white-bellied pangolin; BBP= black-bellied pangolin

III.1.1.4 Knowledge of pangolins' diet composition

Most respondents knew that pangolins feed predominantly on ants (82.6%, n =304; Fig.26) and termites (79.3%, n=292) with a significant difference (χ^2 [X=11, N=339] =4.67, p =0.001), and never on herbs and leaves (Fig. 26). A minority of the respondents reported pangolins to also feed on grasshoppers (7.1%, n=25), on ground (2.6%, n=9), weaves (<1%, n=1), earthworm (2.8%, n=10), butterfly (<1%, n=2), mushroom (1.4%, n=5), maggots (<1%, n=1), and (8.7%, n=28) of respondents do not know what pangolin feed on.

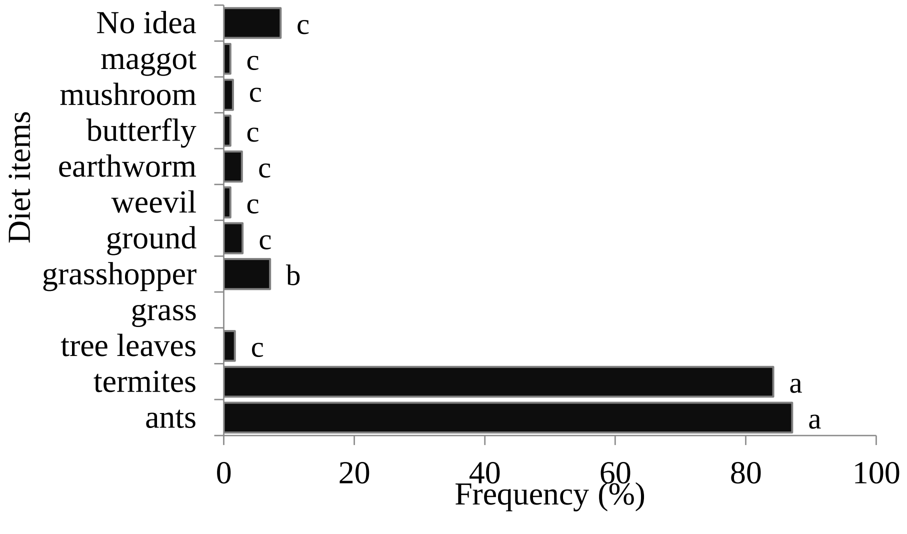


Figure 26: Percentages of the pangolins diet component reported by local people

III.1.2 Pangolin habitats in the surveyed areas

III.1.2.1 Vegetation types

III.1.2.1.1 Types of vegetation formations in both parks

In Mpem et Djim National Park (MDNP) and Deng Deng National Park (DDNP), respectively seven and six different vegetation types were described along 400 km cumulated transect and recce estimated distances. In MDNP, seven vegetation formations, potential habitats of pangolins were described including savanna wetland or saltwork (1.3%; Table V) only in MDNP, woodland savanna (16.70%), grassland savanna (22.0%), swamp (2.0%), forest gallery (7.0%), secondary forest (36.5%) and near primary forest (14.0%). Secondary forest frequency significantly dominated (χ^2=56.49, df=6, p=0.0001). In DDNP, six vegetation types known as woodland savanna (7.01%), grassland savanna (10.99%), swamp (9.0%), gallery forest (2.58%), and secondary forest (31.42%), and near primary forest (55.5%) were described (Table V). Near primary forest frequency significantly (χ^2=106.03, df=5, p=0.0001) the other habitat types.

III.1.2.1.2 Physiognomy of vegetation formations

Near primary forests were relatively younger (immature) in Mpem et Djim national park (Fig. 27a) than in Deng Deng national park. This vegetation formation was characterized by a canopy relatively closed (with up to 50% of closure, Table V) and opened undergrowth made up of shrubs mixt with herbs, and lianas. In near primary forests, the visibility in the undergrowth was relatively opened (up to 10 m). The trees average height usually reaches 25m with a relatively large diameter at breast height (DHB) reaching 3 m.

In the secondary forests (Fig. 27b), the canopy cover was widely opened (with <25% of closure) with a very close undergrowth made up of herbs, lianas, and shrubs and the trees mostly have a relatively small to medium DHB (0.5 to 1.5 m). The undergrowth visibility was very closed (<5m) as compared to swamps where the closed undergrowth is due to a high abundance of rattans *Calamus* spp., (Arecaceae) and Maranthacae.

Gallery forest (Fig. 27c) has relatively opened canopy cover (with <25% of closure) and the undergrowth was constituted mainly with shrubs and lianas as compared to the woodland savanna which was slightly different with very close undergrowth often covered with old or young Bokassa grass, *Chromoleana odorata* (Linnaeus). Gallery forests usually have a small watercourse and sometimes are completely swampy areas of more than 1 km in length. However, the trees in the gallery forest have an average height similar to those in the near primary forest with a diameter at a breast height of ~2 m.

The grassland savanna (Fig. 27d) has typical characteristics of the savanna zone, with no canopy cover (0% of closure). The main characteristic of this habitat was the large distribution of herbs from the family Gramineae up to 3m in height. The grassland undergrowth visibility was 100% closed (no visibility) during rainy season and opened in dry season and early rainy season and characterized mainly by the herbaceous and dotted individual shrubs of not more than 5 m in height. In some areas, shrubs were more heavily distributed than Gramineae and vis versa.

The woodland savannas (Fig. 27e) are intermediary between forest and savanna habitats with a relative opened canopy (<25% of closure). The woodland undergrowth visibility was highly closed somewhere and relatively opened elsewhere. This habitat was mostly characterized by understory by herbaceous commonly called Bokassa grass (no visibility) with the presence of trees which branches were very low and almost undulated at the soil level. Contrary to trees' height recorded in grassland savanna, trees were estimated to be more than 8 m height in woodland.

Swamps (Fig. 27f) with a canopy slightly covered (<25% of closure), were recorded in near primary forests, secondary forests, and gallery forests. Swampy areas are usually encountered near water and streams. This habitat was mainly characterized by its temporary flooded soils, and the large distribution of rattans and Maranthacae (*Megaphynium macrostachyum*, Order of Zingiberales). The swamp undergrowth visibility was very closed (<5m) similar to the secondary forest. However, in swamp, the presence of rattans *Calamus* spp., (Arecaceae) and Maranthacae spp. make the difference with secondary forest.

Saltwork were structured like savanna with very short herbs, without trees, and subsequently, no canopy cover (0% of closure) as compared to grassland savanna. However, saltwork slightly differed from grassland with their soils almost partially or flooded and with a high percentage of salt used by buffalo frequently observed in this habitat. Saltwork were usually found between grassland savannas and edge of gallery forests. Although largely similar to grassland savanna, their physiognomic characteristics differed completely with high visibility in the undergrowth (more than 15 to 200 m) and the presence of water (Fig. 27g). The detailed characteristics of the different types of habitats are presented in the following table.

Table V: Frequency and characteristics of different potential habitat types of pangolins recorded in Mpem et Djim National Park and Deng Deng National Park

Ecosystem	Habitat types	DDNP Fo$_i$% (n)	MDNP Fo$_i$% (n)	Canopy cover (% of closure)	Understory composition	Visibility (distance)	Slope
Forest	Near Primary Forest (NPF)	55.5 (212)^a	14.0 (54)^c	Close (25-50%)	Shrubs + Lianas	Open (6-10m)	Steep
	Secondary Forest (SF)	31.42 (119)^b	36.5 (146)^a	Open (1-25%)	Herbs + shrubs	Very close (<5m)	Gentle
	Swamp (Sw.)	9.0 (35)^c	2.0 (28)^e	Open (1-25%)	Rapphia + Maranthaceae	Very close (<5m)	Gentle
	Gallery Forest (GF)	2.58 (8)^d	7.0 (28)^d	Open (1-25%)	Herbs + shrubs	Open (11-15m)	Gentle
Savanna	Woodland Savanna (WS)	7.01(27)^c	16.70 (68)^c	Open (1-25%)	Herbs + shrubs	Close (6-10m)	Gentle
	Grassland savanna (GS)	10.99 (42)^c	22.0 (88)^b	None (0%)	Herbs	Very close (<5m)	Gentle
	Saltwork (Sl.)	0 (0)	1.5 (20)	None (0%)	Herbs	Very open (>15m)	moderate
	Value of χ^2 p-value	χ^2=106.3 p=0.0001	χ^2=56.49 P=0.0001				
	Total	**100 (443)**	**100 (434)**				

MDNP= Mpem et Djim National Park; DDNP= Deng Deng National Park; Fo$_i$= Frequency of occurrence of the habitat type "i"; n= number of "i" habitat recorded. The numbers into parenthesis in column 3 and 4 are numbers of time each vegetation formation was recorded in the surveyed areas. And the different letters in the same columns indicate significant differences following pairwise comparisons of trapping rates between different habitat types.

The figure 27 shows different potential habitat types of pangolins recorded in both protected areas.

(a) Near primary forest in MDNP

(b) Secondary forest

(c) Gallery Forest near a saltwork

(d) Grassland savanna

(e) Woodland savanna

(f) Swamp

(g) Saltwork (only in MDNP)

(h) Near primary forest in DDNP

Figure 27: Main different types of pangolins' potential habitats recorded in Mpem et Djim National Park and Deng Deng National Park.

III.1.2.1.3 Pangolin habitats

A total of six vegetation formation types were assumed to be potential habitats of pangolins. They include woodland savanna, grassland savanna, swamp, gallery forest, secondary forest, and the near primary forest. The selection of the vegetations relied on (1) the report of local people during the questionnaire survey and (2) the encounter rate of suspected pangolin presence signs found in each habitat. The signs of pangolins' presence frequently recorded included mainly (1) active living and feeding burrows mostly encountered in the savanna areas, and also (2) feeding sites e.g., termite mounds with scathes and other feeding marks on the ground, and on dead fallen wood and standing dead tree trunks. In the forest zone, fallen tree trunks with termites and the signs of feeding activities were mostly recorded and therefore considered as potential feeding sites for pangolin and as pathways.

III.1.2.2 Confirmation of pangolins presence

III.1.2.2.1 Presence of giant and white-bellied pangolins

Of 5,889 independent photographic events of large- to medium-sized mammals over 10,887 operational camera trap nights in Mpem et Djim National Park (MDNP) and Deng Deng National Park (DDNP). 355 photographic events (3.26%) of white-bellied pangolin were recorded in six different habitat types including Near Primary Forest (NPF), Secondary Forest (SF), Swamp (Sw.), Gallery Forest (GF), Woodland Savanna (WS), and Grassland savanna (GS) in both national parks (Fig. 28).

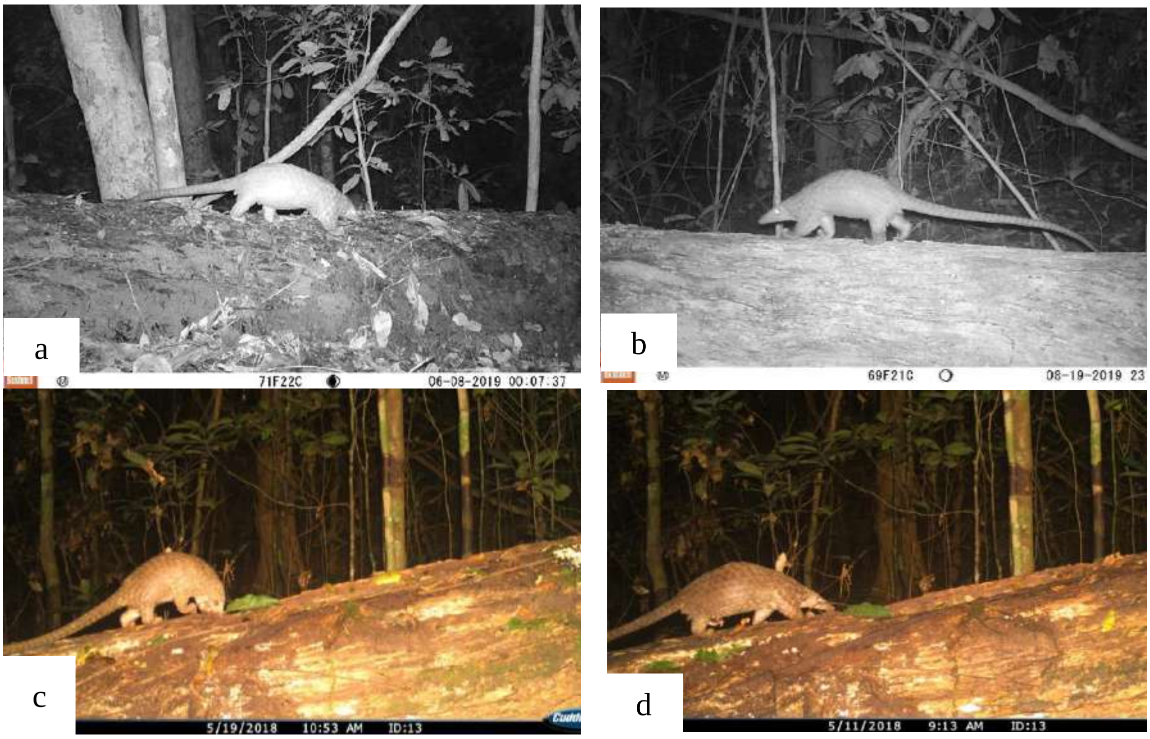


Figure 28: Evidence of white-bellied pangolin presence in the surveyed area habitats a) White-bellied crossing the log in SF, b) White-bellied pangolin crossing a log in SF, c) White-bellied foraging on the log in NPF, d) White-bellied crossing the log in NPF.

For giant pangolin, we recorded 32 events (0.29%) in four different habitat types including Grassland Savanna (GS), Gallery Forest (GF), Woodland Savanna (WS), and Secondary Forest (SF). The figure 30 shows evidence of giant pangolin presence in the surveyed area habitats.

Figure 29: Evidence of giant pangolin's presence in the surveyed area habitats a) giant pangolin inspecting the soil near a burrow in the GS (MDNP), b) giant pangolin near a termite's mounds in GF (MDNP), c) giant pangolin near termite's mounds in WS (DDNP) and d) giant pangolin juvenile returning to burrow in GF (DDNP).

III.1.2.2.2 Presence of black-bellied pangolin

No evidence of black-bellied pangolin presence was recorded during the survey period.

III.1.2.2.3 Pangolin capture rate

The capture rate of white-bellied pangolin was the highest of all pangolin species, comprising 6.02% of total captured events, followed by the giant pangolin representing 0.54% of total captured events (see Table VI). The capture rate of black-bellied pangolin was null.

II.1.2.2.4 Pangolin capture probability

Overall capture probability (CP) of the white-bellied pangolin was 0.033 (Table VI) per camera trap day, this is one event recorded every 33 days (this is 1/CP). For giant pangolin a capture probability was 0.003 per camera trap day, this is one event recorded every 333 days.

Table VI : Relative frequency of capture rate and trapping rate, and capture probability of each pangolin species

Pangolin species	SE	NPE	TNASE	TR (%)	CR (%)	CP	1/CP (days)
White-bellied pangolin	10,887	355	5,889	3.220	6.028	0.033	33
Giant pangolin	10,887	32	5,889	0.290	0.543	0.003	333
Black-bellied pangolin	10,887	0	5,889	-	0.000	-	-

NPE= Number of pangolin events; TR=Trapping rate; TNASE= Total number of all media to large-sized mammal species events recorded; SE= Sampling effort; CR= capture rate of pangolin; CP= Capture probability.

III.1.2.2.5 Trapping rate of pangolins

III.1.2.2.5.1 Trapping rate of giant pangolin

III.1.2.2.5.1.1 Variation of tapping rate between protected areas

A total of 3,444 operational camera trap nights were accumulated on non-log targets including burrows, feeding signs, termite mounds, etc in Deng Deng National Park (DDNP), and 3,981 trap nights in Mpem et Djim National Park (MDNP). The trapping rates of Giant Pangolin (GP) in both national parks were relatively lower compared to that of White-bellied pangolin (WBP). The highest trapping rate of GP was recorded in MDNP (0.53%, 21 events), while the lower rate 0.32%, (11 events) was recorded in DDNP with no significant difference between both parks.

III.1.2.2.5.1.2 Effect of habitat type on giant pangolin trapping rate

Gallery forests (GF) in both parks and grassland savanna (GS) of Mpem et Djim National Park (MDNP) recorded the highest giant pangolin trapping rates (TR >1%, which is 2 and 4 events in GF and 8 events in GS, respectively) with no significant difference ($p \geq 0.05$) followed by the woodland savanna in both parks (>0.4%). The grassland savanna of Deng Deng National Park (DDNP) and the secondary forest of both parks recorded the lowest trapping rates (<0.3%). No event of giant pangolin was recorded in near primary forest and swamp habitats of both parks (see Table VII).

Table VII: Variation of trapping rate of giant pangolin in the habitats of each park

	DDNP		**MDNP**			
Habitat types	**SE**	**TR**	**SE**	**TR**	Value of χ^2	p-value
Gallery forest	207	**1.93 (4)**	193	**1.04 (2)**	$\chi^2=0.27$	p=0.61
Grassland savanna	1,052	0.19 (2)	615	**1.3 (8)**	$\chi^2=1.42$	p=0.23
Near primary forest	362	0 (0)	287	0 (0)	-	-
Secondary forest	462	0.22 (1)	2,044	0.24 (5)	$\chi^2=0.008$	p=0.97
Swamp	434	0 (0)	95	0 (0)	-	-
Woodland savanna	927	0.43 (4)	747	0.8 (6)	$\chi^2=0.11$	p=0.73
Value of χ^2		$\chi^2=5.88$		$\chi^2=2.77$		
p-value		p=0.31		p=0.73		
Total	3,444	0.32 (11)	3,981	0.53 (21)	$\chi^2=0.05$	p=0.81

SE= Sampling effort; TR= Trapping rate; MDNP= Mpem et Djim National Park; DDNP= Deng Deng National Park; The numbers in brackets are the numbers of independent photographic events recorded. The numbers in bold denote the higher trapping rates.

III.1.2.2.5.1.3 Seasonal variation of giant pangolin trapping rate

Overall, the Giant Pangolin (GP) trapping rate was higher during the rainy season (0.55%, 22 events) than in the dry season (0.29%, 10 events) with not significant difference ($\chi^2=0.06$; df=1; p=0.79). Gallery forest trapping rate was highest during the rainy season (2.59%, 5 events; Table

VIII), followed by grassland savanna and woodland savanna. Except for secondary forest, the trapping rates of GP in all habitat types were lower during dry season (see Table VIII).

Table VIII: Trapping rate of giant pangolin in habitats during seasons

	Dry		**Rainy**			
Habitat types	SE	TR	SE	TR	Value of χ^2	p-value
Gallery forest	207	0.48 (1)	193	**2.59 (5)**	χ^2=1.45	p=0.22
Grassland savanna	1,052	0.19 (2)	615	**1.3 (8)**	χ^2=1.42	p=0.23
Near primary forest	362	0 (0)	287	0 (0)	-	-
Secondary forest	462	0.65 (3)	2,044	0.15 (3)	χ^2=0.37	p=0.51
Swamp	434	0 (0)	95	0 (0)	-	-
Woodland savanna	927	0.43 (4)	747	0.8 (6)	χ^2=0.11	p=0.73
Value of χ^2	-	χ^2=1.25	-	χ^2=4.57		
p-value	-	p=0.74	-	p=0.33		
Total	3,444	0.29 (10)	3,981	**0.55 (22)**	χ^2=0.06	p=0.79

SE= Sampling effort; TR= Trapping rate; The numbers into brackets are the numbers of independent photographic events recorded. The numbers in bold denote the higher trapping rates.

III.1.2.2.5.1.4 Annual variation of trapping rate

A total of 2,074 operational camera trap nights were accumulated in 2018, 2,415 in 2019, and 2,936 in 2020. The highest trapping rate of Giant Pangolin (GP) was recorded during 2018 (0.82%, 17 events), followed by 2020 (0.34%, 10 events), and lower in 2019 (0.21%, 5 events). The habitats of savanna zones [Gallery Forest (GF), Grassland savanna (GS) and Woodland savanna (WS)] had relatively highest trapping rates over the three years of the survey. Secondary Forest recorded the lower trapping every year. Overall, trapping rates over the surveyed years was non-significantly different (χ^2=0.43; df=2; p=0.80; see Table IX).

Table IX: Annual trapping rate of giant pangolin per habitat type

	2018		**2019**		**2020**			
Habitat types	SE	TR	SE	TR	SE	TR	Value of χ^2	p-value
Gallery forest	193	1.04 (2)	96	**3.13 (3)**	111	0.9 (1)	χ^2=1.84	p=0.39
Grassland savanna	615	**1.3 (8)**	482	0 (0)	570	0.35 (2)	χ^2=1.65	p=0.63
Near primary forest	195	0 (0)	195	0 (0)	259	0 (0)	-	-
Secondary forest	131	0.76 (1)	1,102	0.18 (2)	1,273	0.24 (3)	χ^2=0.51	p=0.77
Swamp	193	0 (0)	0	0 (0)	336	0 (0)	.	.
woodland savanna	747	0.8 (6)	540	0 (0)	387	**1.03 (0.4)**	χ^2=1.22	p=0.54
Total	2,074	0.82 (17)	2,415	0.21 (5)	2,936	0.34 (10)	χ^2=0.43	p=0.80

SE= Sampling effort; TR= Trapping rate; The numbers in brackets are the numbers of independent photographic events recorded. The numbers in bold denote the higher trapping rates.

III.1.2.2.5.2 Trapping rate of white-bellied pangolin

III.1.2.2.5.2.1 Variation of tapping rate between protected areas

A total of 4,184 operational camera trap nights were accumulated on all placement target types in DDNP and 6,703 trap nights in MDNP. The trapping rate of WBP (3.55%, 238 events) was higher in MDNP than in DDNP (2.75%, 115 events) with not significant difference between both protected areas (χ^2=0.10; df=1; p=0.74).

III.1.2.2.5.2.2 Effect of habitat type on white-bellied pangolin trapping rate

Deng Deng National Park's near the primary forest recorded a significantly higher (χ^2=37.21; df=5; p=0.0001) trapping rate of white-bellied pangolin (12.27%, 74 events) than in other habitat types; followed by the secondary forest (2.41%, 21 events) and swamp. Secondary Forest (SF) trapping rate (5.07%, 209 events) was significantly (χ^2=11.52; df=5; p=0.04) higher in Mpem et Djim National Park than all habitat types. The savanna habitats (GS, WS, GF) of both protected areas recorded lower trapping rates (<0.1%, with 1-3 events). White-bellied pangolin events were recorded in all habitats except the grassland savanna in Mpem et Djim National Park and the gallery forest in Deng Deng National Park (Table X).

Table X: Trapping rate of white-bellied pangolin in the habitat types across protected areas

	DDNP		**MDNP**			
Habitat types	**SE**	**TR**	**SE**	**TR**	Value of χ^2	p-value
Gallery forest	207	0 (0)	193	0.52 (1)^{c}	χ^2=0.42	p=0.57
Grassland savanna	1,052	0.19 (2)^{c}	615	0 (0)	χ^2=0.19	p=0.67
Near primary forest	603	**12.27 (74)$^{a/A}$**	930	**2.58 (24)$^{b/B}$**	χ^2=6.32	p=0.01
Secondary forest	873	**2.41 (21)^{b}**	4,123	**5.07 (209)^{a}**	χ^2=1.09	p=0.30
Swamp	522	**1.72 (9)^{b}**	95	1.05 (1)^{b}	χ^2=0.16	p=0.69
Woodland savanna	927	0.97 (9)^{c}	747	0.4 (3)^{c}	χ^2=0.24	p=0.63
Value of χ^2	-	χ^2=37.21	-	χ^2=11.52	-	-
p-value	-	p<0.0001	-	p=0.04	-	-
Total	4,184	2.75 (115)	6703	3.55 (238)	χ^2=0.10	p=0.74

SE= Sampling Effort; TR= Trapping rate; MDNP= Mpem et Djim National Park; DDNP= Deng Deng National Park. The numbers into brackets are the numbers of independent photographic events recorded. The numbers in bold denote the highest trapping rates. Low case letters in columns and capital letters in rows indicate significant differences following pairwise comparisons of trapping rates between habitat types.

III.1.2.2.5.2.3 Seasonal variation of white-bellied pangolin tapping rate

The white-bellied pangolin trapping rates in the rainy season (3.23%, 200 events) and dry season (3.26%, 153 events; Table XI) were not significantly different (χ^2=0.00; df=1; p=0.99). However, near primary forests had similar highest trapping rates in both seasons, while savanna habitats [Grassland Savanna (GS), Woodland Savanna (WS)] and Gallery Forest (GF) trapping rates were low to null during both rainy and dry seasons (Table XI).

Table XI: Trapping rate of white-bellied pangolin per habitat type during the dry and rainy seasons

	Dry		Rainy			
Habitat types	**SE**	**TR**	**SE**	**TR**	Value of χ^2	p-value
Gallery forest	111	0 (0)	289	0.35 (1)	χ^2=0.35	p=0.55
Grassland savanna	570	0.18 (1)	1,097	0.09 (1)	χ^2=0.03	p=0.86
Near primary forest	650	**6.46 (42)**	883	**6.34 (56)**	χ^2=0.00	p=0.97
Secondary forest	2,615	**3.94 (105)**	2,381	**5.33 (127)**	χ^2=0.21	p=0.65
Swamp	359	1.11 (4)	258	2.33 (6)	χ^2=2.02	p=0.16
woodland savanna	387	0.78 (3)	1,287	0.7 (9)	χ^2=0.00	p=0.95
Total	4,692	3.26 (155)	6,195	3.23 (200)	χ^2=0.00	p=0.99

SE= Sampling Effort; TR= Trapping rate. The numbers in bold denote the higher trapping rate.

III.1.2.2.5.2.4 Annual variation of trapping rate

White-bellied pangolin trapping rates were higher in 2019 (3.40%, 157 events) and 2020 (3.62%, 139 events) and lower in 2018 (2.33%, 57 events) with no significant differences (χ^2=0.36; df=2; p=0.83; Table XII). The forest habitats [Secondary Forest (SF) and Near Primary Forest (NPF)] had the highest trapping rates during the surveyed years. The savanna habitats [Grassland savanna (in 2018, 2019) and Gallery Forest (in 2018) and swamp (in 2019)] trapping rates were lower to null.

Table XII: Annual trapping rate of white-bellied pangolin in habitat types

	2018		2019		2020			
Habitat types	SE	TR	SE	TR	SE	TR	Value of χ^2	p-value
Gallery Forest	193	0.52 (1)	107	0 (0)	100	0 (0)	χ^2=1.04	p=0.59
Grassland savanna	615	0 (0)	567	0.18 (1)	493	0.2 (1)	χ^2=0.19	p=0.91
Near Primary Forest	303	**12.54 (38)**	723	**3.18 (23)**	507	**7.3 (37)**	χ^2=5.73	p=0.05
Secondary Forest	326	3.07 (10)	2,568	**4.91 (126)**	2,102	**4.47 (94)**	χ^2=0.45	p=0.80
Swamp	258	1.94 (5)	55	1.82 (1)	304	1.32 (4)	χ^2=2.02	p=0.16
Woodland savanna	747	0.4 (3)	595	1.01 (6)	332	0.9 (3)	χ^2=0.13	p=0.94
Total	2,442	2.33 (57)	4,615	3.4 (157)	3,838	3.62 (139)	χ^2=0.36	p=0.83

SE= Sampling Effort; TR= Trapping rate; The numbers into brackets are the numbers of independent photographic events recorded. The number in bold denotes the highest trapping rate.

III.1.2.3 Pangolin behavior

III.1.2.3.1 Giant pangolin behavioral activity

Giant pangolin (GP) activities defining behavior of this species mostly include individuals observed passing near the targets (7.36%; 19 events). Passing was significantly higher (χ^2=11.86, df=3, p=0.007) than other activities including, entering or/and exiting the burrow (0.06%; 4 events), inspecting the burrow (0.78%; 2 events), and foraging (2.72%; 7 events; Fig. 30a). No evidence of

GP individual eating activity was recorded. Figure 31a shows the trapping rates of different activities of giant pangolin observed.

III.1.2.3.1.1 Effect of placement target type of giant pangolin behavioral activity

The behavior of giant pangolin (GP) described, mainly includes nesting and foraging activities through passing (7.36%; 19 events) and foraging near the targets (2.72%; 7 events). Foraging events of GP were recorded on feeding sites on standing trunks, termite mounds and more on living burrows (1.55%; 4 events; see Table XIII). The GP trapping varied according to target type. GP mostly passed near burrows (3.49%; 9 events) and was rarely observed entering the burrow (only one video showing individual entering in borrow) and photos displaying pangolin individual inspecting burrow (0.78%, 2 events), departing or returning to the burrow (0.06%, 4 events). There was no statistical difference ($p \geq 0.05$) of GP trapping rates between placement targets.

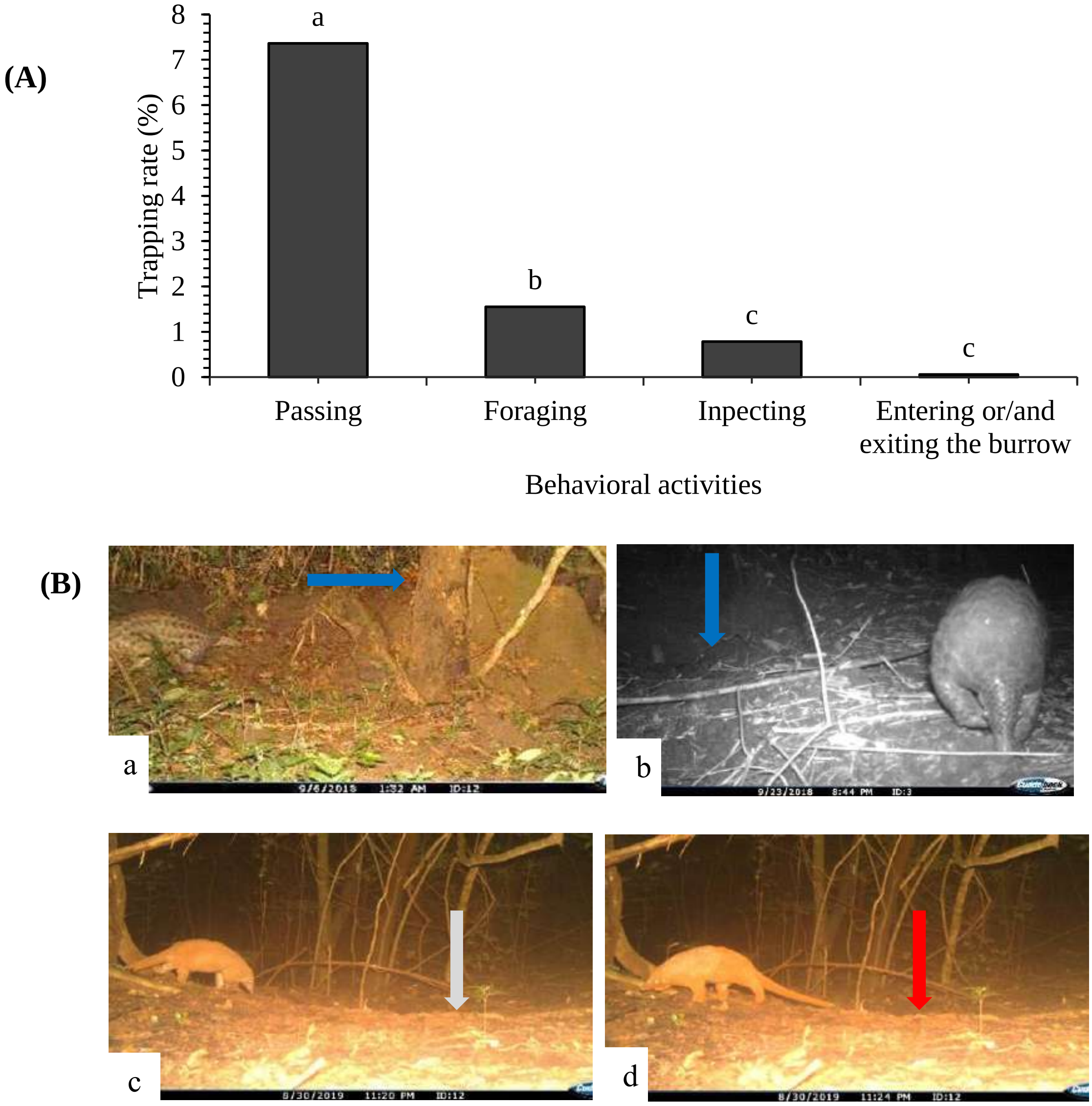


Figure 30: Different activities of giant pangolin observed: (A) trapping rate of each activity; the different letters on histogram frequency values indicate significant differences following pairwise comparisons of trapping rates between different activities. (B) some activities observed on camera trap photos: (a) Foraging activity near termite mound; (b) Foraging activity near living burrow; (c) individual returning to burrow or passing; (d) departing from burrow.

Table XIII: Trapping rate of giant pangolin behavioral activities on different placement targets

		Placement target types						Value of χ^2	p-value	Total
		FB	**FSST**	**LB**	**DTWT**	**TM**	**TH**			
SE	→	258	1284	2636	2655	290	818			7941
Behavioral activities	Entering and exiting	0 (0)	0 (0)	0.06 (4)	0 (0)	0 (0)	0 (0)	χ^2=0.3	p=0.99	0.06 (4)^{c}
	Foraging	0 (0)	0.39 (1)	**1.55 (4)**	0 (0)	0.78 (2)	0 (0)	χ^2=4.26	p=0.51	2.72 (7)^{b}
	Inspecting	0 (0)	0 (0)	0.78 (2)	0 (0)	0 (0)	0 (0)	χ^2=3.9	p=0.56	0.78 (2)^{c}
	Passing	0.39 (1)	1.16 (3)	3.49 (9)	0.39 (1)	1.55 (4)	0.39 (1)	χ^2=5.97	p=0.31	7.36 (19)^{a}
	Value of χ^2	χ^2=1.56	χ^2=3.28	χ^2=4.45	χ^2=1.17	χ^2=2.84	χ^2=1.56	-	-	χ^2=11.8
	p-value	p=0.81	p=0.51	p=0.21	p=0.76	p=0.41	p=0.81	-	-	p=0.007
	Total	0.39 (1)^{c}	1.55 (4)^{b}	7.36 (19)^{a}	0.39 (1)^{c}	2.33 (6)^{b}	0.39 (1)^{c}	χ^2=17.7	p=0.003	12.4 (32)

SE= Sampling Effort; FB= feeding burrow FSST=Feeding site on the standing tree; GFS=Ground feeding sites; LB= Living burrow; DTWT=Decaying trunks with termites; TM=Termite mound; TH= Tree hollow. The numbers in bold denote higher trapping rates. The numbers into brackets are the numbers of independent photographic events. The different letters in row or total's column indicate significant differences of trapping rates between different placement target types.

III.1.2.3.1.2 Effect of habitat type of giant pangolin activity

The main Giant pangolin's (GP) behavioral activities, including foraging and passing activities occurred most frequently in Woodland Savanna (WS), Grassland Savanna (GS), Gallery Forest (GF), and Secondary Forest (SF; Table XIV). Overall, the highest trapping rates occurred in GS and WS habitats (2.5%; 10 events), followed by GF and SF (1.5%; 6 events) with not significant difference. The GP activity was not recorded in Near Primary Forest (NPF) and Swamp (SW). One camera trap installed in the GF recorded a giant pangolin destroying a termite's mound (see Fig. 31).

Table XIV: Trapping rate of giant pangolin activities across habitat types

		Habitat types						Value of χ^2	p-value	Total
		GF	**GS**	**NPF**	**SF**	**Sw.**	**WS**			
	SE →	400	1667	1533	2498	617	1674			8389
Behavioral activities	Entering and exiting	0.5 (2)	0.5 (2)	0 (0)	0 (0)	0 (0)	0 (0)	χ^2=2.00	P=0.85	1.0 (4)
	Foraging	**0.25 (1)**	**0.5 (2)**	0 (0)	0.25 (1)	0 (0)	**0.75 (3)**	χ^2=1.46	P=0.91	1.75 (7)
	Inspecting	0 (0)	0.25 (1)	0 (0)	0 (0)	0 (0)	0.25 (1)	χ^2=1.0	P=0.96	0.5 (2)
	Passing	0.75 (3)	**1.25 (5)**	0 (0)	**1.25 (5)**	0 (0)	**1.5 (6)**	χ^2=2.75	P=0.74	4.75 (19)
	Value of χ^2	χ^2=0.5	χ^2=0.9	-	χ^2=2.83	-	χ^2=2.1	-	-	χ^2=5.43
	p-value	P=0.92	P=0.83	-	P=0.40	-	P=0.55	-	-	P=0.14
	Total	1.5 (6)	2.5 (10)	0 (0)	1.5 (6)	0 (0)	2.5 (10)	χ^2=4.75	P=0.44	8 (32)

SE: Sampling Efforts; Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The numbers into brackets are the numbers of independent photographic events recorded. The numbers in bold denote higher trapping rates.

Figure 31: Giant pangolin foraging and feeding activities recorded in Mpem et Djim National Park's gallery forest: a) termite mound with scratches at the installation date, b) mound view at camera side, c) pangolin departing from the mound, d) pangolin going towards termite mound, e) termite mound height reduced, f) termite mound almost destroyed.

III.1.2.3.1.3.1 Variation among target types

Overall, Giant pangolin (GP) behavioral activities were not significantly different (χ^2=0.16 df=1; p=0.68) between the rainy (1.81%; 22 events) and the dry season (1.11%; 10 events). Combining all placement sites, GP passing activity was higher during the rainy season than in the dry season and most frequently recorded on living burrows (0.58%; 7 events; Table XV). Foraging activity was mainly recorded on living burrows (0.33%; 4 events), and on termite mounds (0.08%; 1 event) in the rainy season (see Table XV). The Generalized Linear Models (GLMs) results show that placement target and animal activity types significantly influenced the trapping rate of giant pangolin. Moreover, the GP behavioral activities have not varied significantly on target between rainy and dry seasons. The best models that predicted the GP frequency of activity (detection) included placement target types and animal activity (the lowest AIC=70.79 and AIC=87.95 respectively; Table XV).

Table XV: Generalized Linear Models showing seasonal variation of giant pangolin behavioral activities trapping rate among placement target types

		Placement targets						
		FB	**FSST**	**LB**	**DTWT**	**TM**	**TH**	**Total**
Dry	**SE** →	899	680	770	1382	26	389	4146
Behavioral activities	Entering and exiting	0 (0)	0 (0)	0.11 (1)	0 (0)	0 (0)	0 (0)	0.11 (1)
	Foraging	0 (0)	0.11 (1)	0 (0)	0 (0)	0.11 (1)	0 (0)	0.22 (2)
	Passing	0 (0)	0.22 (2)	0.22 (2)	0 (0)	0.33 (3)	0 (0)	0.78 (7)
	Total	**0 (0)**	**0.33 (3)**	**0.33 (3)**	**0 (0)**	**0.44 (4)**	**0 (0)**	**1.11 (10)**
Rainy	**SE** →	**1214**	**595**	**1866**	**1281**	**264**	**429**	**5649**
Behavioral activities	Entering and exiting	0 (0)	0 (0)	0.96 (3)	0 (0)	0 (0)	0 (0)	0.96 (3)
	Foraging	0 (0)	0 (0)	0.33 (4)	0 (0)	0.08 (1)	0 (0)	0.41 (5)
	Inspecting	0 (0)	0 (0)	0.16 (2)	0 (0)	0 (0)	0 (0)	0.16 (2)
	Passing	0.08 (1)	0.08 (1)	0.58 (7)	0.08 (1)	0.08 (1)	0.08 (1)	0.99 (12)
	Total	**0.08 (1)**	**0.08 (1)**	**1.32 (16)**	**0.08 (1)**	**0.16 (2)**	**0.08 (1)**	**1.81 (22)**

Model factors	***df***	**RD**	**p (χ^2)**	**AIC**
Season	1	1.82	0.17	118.32
Behaviour	4	15.86	0.003	87.95
Target	5	37.34	0.0001	70.79
Season*Target	5	11.03	0.04	89.93
Season*Behaviour	1	0.15	0.69	89.93
Behaviour*Target	20	8.96	0.98	114.32
Season*Behaviour* Target	5	2.04	0.84	122.9

df=degrees of freedom, RD= residual deviance, P(χ^2) Chi-square p-value, AIC= Akaike Information Criterion, SE= Sampling Effort; FB= feeding burrow; FSST=Feeding site on standing tree; GFS=Ground feeding sites; LB= Living burrow; DTWT=Decaying trunks with termites; TM=Termite mound; TH= Tree hollow. The numbers into brackets are the numbers of independent photographic events recorded.

III.1.2.3.1.3.2 Variation among habitat types

During the dry season, foraging activity of giant pangolin (GP) was low in WS and SF (0.9%; 1 event) and null in all other habitat types. The foraging activity was higher during the rainy season in savanna habitats [Grassland Savanna (0.69%; 2 events), Gallery Forest (1.39%; 4 events), and Woodland Savanna (0.69%; 2 events)] than in other habitat types. Overall, the GP passing activity was observed most frequently in Grassland Savanna, Secondary Forest, and Woodland Savanna during both rainy and dry seasons (Table XVI). The Generalized Linear Models (GLMs) results show that the habitat types significantly influenced the trapping rate of each giant pangolin activity. The GP behavioral activities did not vary significantly between rainy and dry seasons. The best model that predicted the GP frequency of activity included only habitat type (the lowest AIC=78.28; Table XVI).

Table XVI: Generalized Linear Models showing seasonal variation of giant pangolin behavioral activities among habitat types

		Habitat types						
		GF	**GS**	**NPF**	**SF**	**Sw.**	**WS**	**Total**
Dry	**SE** →	111	570	650	1,307	359	387	**3,384**
Behavioral activities	Entering and exiting	0.9 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.9 (1)
	Foraging	0 (0)	0 (0)	0 (0)	0.9 (1)	0 (0)	0.9 (1)	0.18 (2)
	Passing	0 (0)	1.8 (2)	0 (0)	1.8 (2)	0 (0)	2.7 (3)	6.31 (7)
	Total	**0.9 (1)**	**1.8 (2)**	**0 (0)**	**2.7 (3)**	**0 (0)**	**3.6 (4)**	**9.01 (10)**
Rainy	**SE** →	289	1097	883	1190	258	1287	**5,004**
Behavioral activities	Entering and exiting	0.35 (1)	0.69 (2)	0 (0)	0 (0)	0 (0)	0 (0)	1.04 (3)
	Foraging	1.39 (4)	0.69 (2)	0 (0)	0 (0)	0 (0)	0.69 (2)	2.77 (8)
	Inspecting	0 (0)	0.35 (1)	0 (0)	0 (0)	0 (0)	0.35 (1)	0.69 (2)
	Passing	0 (0)	1.04 (3)	0 (0)	1.04 (3)	0 (0)	1.04 (3)	4.15 (12)
	Total	**1.73 (5)**	**2.77 (8)**	**0 (0)**	**1.04 (3)**	**0 (0)**	**2.08 (6)**	**7.61 (22)**

Model factors	***df***	**RD**	**p (χ^2)**	**AIC**
Season	1	0.19	0.66	82.66
Behaviour	4	3.89	0.42	85.37
Habitat	5	12.56	0.02	78.28
Season*Habitat	5	4.79	0.44	85.3
Season*Behaviour	1	3.01	0.08	85.75
Behaviour*Habitat	20	19.56	0.48	109.04
Season*Behaviour* Habitat	5	0	1	118.83

df=degrees of freedom, RD= residual deviance, P(χ^2) Chi-square p-value, AIC= Akaike Information Criterion, SE: Sampling Efforts; GF= Gallery Forest; NPF= Near Primary Forest; WS= Woodland Savanna; Sl.=Saltworks; GS= Grassland Savanna; Sw.= Swamp. The numbers into brackets are the numbers of independent photographic events recorded.

III.1.2.3.1.4 Annual variation of giant pangolin behavioral activities among habitat types

Globally, Giant Pangolin (GP) foraging activity was higher during 2018 (2.59%, 5 events), and 2020 (0.18%, 2 events) with no significant difference (χ^2=2.09 df=2; p=0.14), while no foraging activity occurred in 2019. However, GP infrequently foraged in savanna habitats [Gallery Forest (0.52%; 1 event), Grassland Savanna (1.04%; 2 events), and Woodland Savanna (1.04%; 2 events)] and secondary forest during 2018, and 2020. GP frequently passing trend was similar to foraging in savanna habitats [Gallery Forest (0.52%; 1 event), Grassland Savanna (1.55%; 3 events), and Woodland Savanna (1.53%; 3 events)] and secondary forest (0.52%; 1 event) during 2018, and more rarely in 2019 and 2020 (see Table XVII).

The Generalized Linear Models results on Giant Pangolin (GP) frequency of activity showed a significant effect of habitat and activity types (behavior) on the trapping rate. The GP activities were observed more often in savanna habitats (Gallery Forest, Grassland Savanna, and Woodland Savanna) than in forest habitats [Near Primary Forest (NPF), Secondary Forest (SF), and Swamp (SW)]. The model that includes giant pangolin behavior and habitat types significantly influenced the trapping rate, while the surveyed year did not influence the activities' trapping rate. The best models that predicted the GP frequency of activity included the year and habitat type (the lowest AIC=114.90; Table XVII).

Table XVII: Generalized Linear Models showing the annual variation of giant pangolin behavioral activities in the surveyed habitat types

		Habitat types						
		GF	**GS**	**NPF**	**SF**	**Sw.**	**WS**	**Total**
2018	**SE** →	193	615	303	326	258	747	2442
Behavioral activities	Exiting	0 (0)	1.04 (2)	0 (0)	0 (0)	0 (0)	0 (0)	1.04 (2)
	Foraging	**0.52 (1)**	**1.04 (2)**	0 (0)	0 (0)	0 (0)	**1.04 (2)**	2.59 (5)
	Inspecting	0 (0)	0.52 (1)	0 (0)	0 (0)	0 (0)	0.52 (1)	1.04 (2)
	Passing	0.52 (1)	1.55 (3)	0 (0)	0.52 (1)	0 (0)	1.55 (3)	4.15 (8)
	Total	1.04 (2)	4.15 (8)	0 (0)	0.52 (1)	0 (0)	3.11 (6)	**8.81 (17)**
2019	**SE** →	96	482	580	1037	0	540	**2735**
Behavioral activities	Entering and exiting	1.04 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.04 (1)
	Foraging	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Passing	2.08 (2)	0 (0)	0 (0)	2.08 (2)	0 (0)	0 (0)	4.17 (4)
	Total	3.13 (3)	0 (0)	0 (0)	2.08 (2)	0 (0)	0 (0)	**5.21 (5)**
2020	**SE** →	**111**	**570**	**650**	**1298**	**359**	**387**	**3375**
Behavioral activities	Entering	0.9 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.9 (1)
	Foraging	0 (0)	0 (0)	0 (0)	**0.9 (1)**	0 (0)	0.9 (1)	0.18 (2)
	Passing	0 (0)	1.8 (2)	0 (0)	1.8 (2)	0 (0)	2.7 (3)	6.31 (7)
	Total	0.9 (1)	1.8 (2)	0 (0)	2.7 (3)	0 (0)	3.6 (4)	**9.01 (10)**

Model factors	***df***	**RD**	**p (χ^2)**	**AIC**
Year	1	0.66	0.41	128.02
Behaviour	4	12.76	0.01	121.92
Habitat	5	27.97	0.0001	108.71
Year*Habitat	5	5.15	0.39	114.90
Year*Behaviour	5	5.15	0.39	133.32
Behaviour*Habitat	20	19.53	0.48	125.50
Year*Behaviour* Habitat	5	2.04	0.84	122.09

df=degrees of freedom, RD= residual deviance, P(χ^2) Chi-square p-value, AIC= Akaike Information Criterion, SE: Sampling Efforts; Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; SL=Saltworks; GS=Grassland Savanna; SW= Swamp. The numbers into brackets are the number of independent photographic events recorded.

III.1.2.3.1.5 Giant pangolin behavioral activity patterns

Activity patterns shown that all GP individuals were mostly nocturnal. Their activities extend from 7:00 PM to 5:00 AM (Fig. 33), although one event was recorded at 5:00 PM. The GP was frequently observed foraging and passing, and rarely entering, exiting, or inspecting burrows rather than departing from or returning to the burrow. The different activity periods overlap over the night with a peak of pangolin passing recorded at 00:00 AM (see Fig. 32).

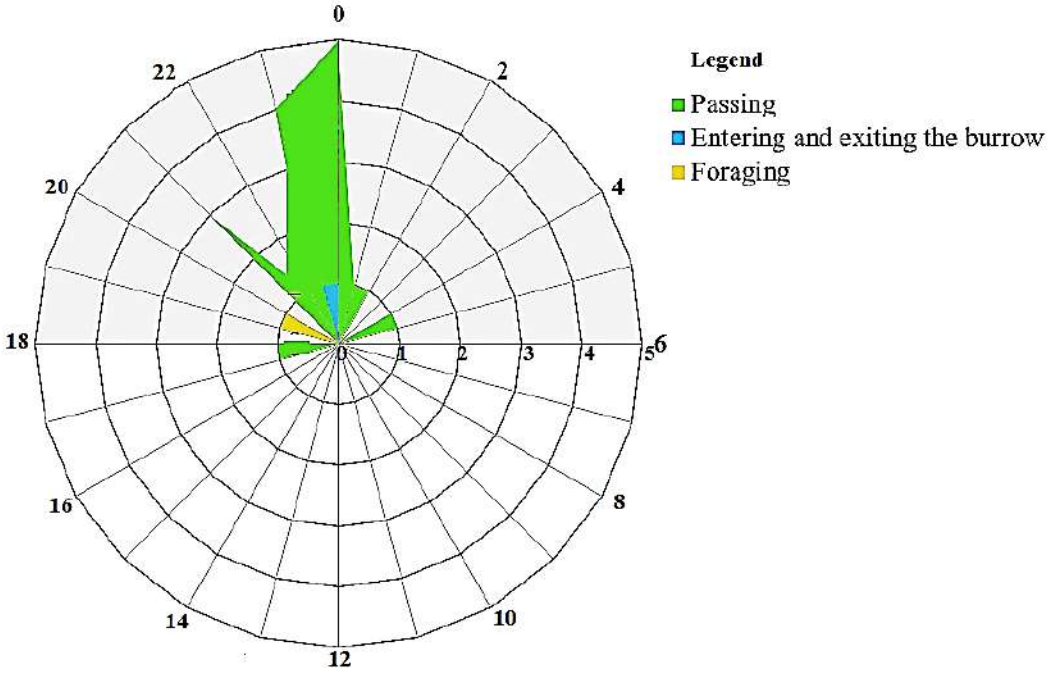


Figure 32: Radial plot showing overlapping of the activity patterns of giant pangolin. The numbers surrounding the circle are hours and those ranging from 0 to 5 on each circle are the numbers of independent photographic events.

Foraging activity recorded frequently occurred at 7:00 PM with very few events (3 events). Giant pangolin was observed once inspecting burrows (see Fig. 34a). One GP individual was observed entering the burrow (1 event) and other individuals were observed departing from or returning to the burrow between 11:00 PM and 12:00 AM (Fig. 34b).

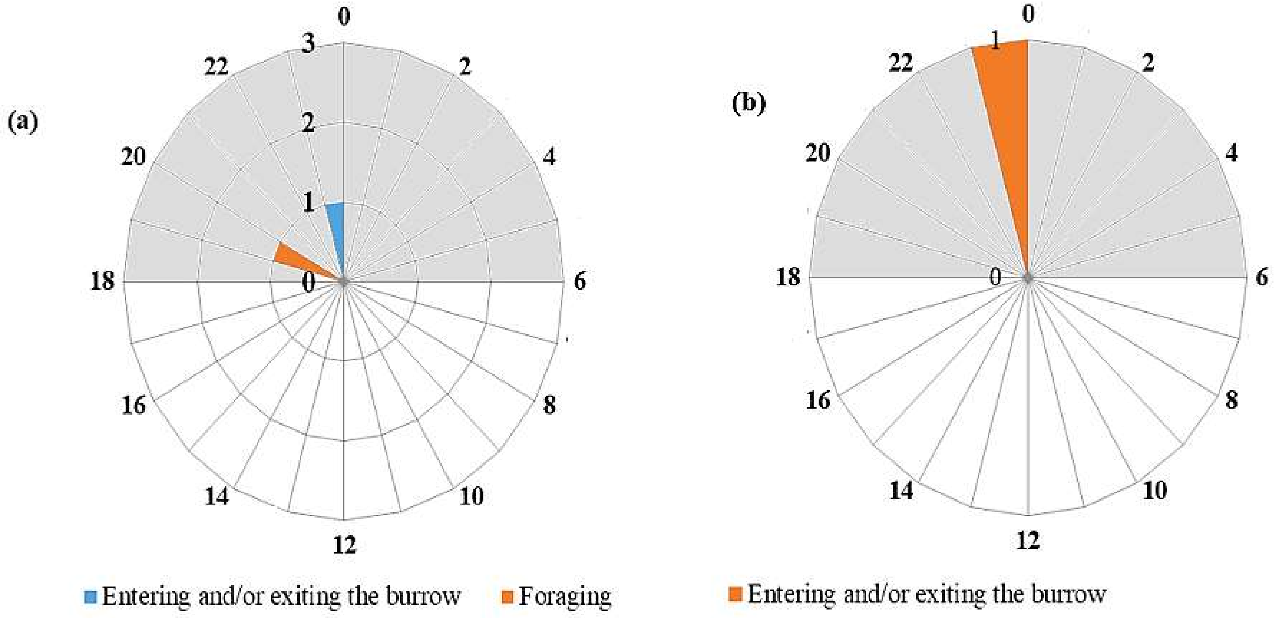


Figure 33: Radial plot showing overlap of giant pangolin activity patterns (a) foraging and entering or/and exiting burrow; (b) inspecting burrows and entering or/and exiting burrow. The numbers surrounding the external circle are hours and those ranging from 0 to 3 are the numbers of independent photographic

III.1.2.3.1.5 Giant pangolin habitat selectivity

In DDNP, gallery forest (GF) was used almost proportionally (W=0.748; Table XVIII) to its availability while being negatively selected in MDNP. However, it has been selected in DDNP, by the giant pangolin (GP) with about three times the probability of the other habitat types (this is one event recorded per day; Table XVIII). In MDNP, the probability to record giant pangolin in GF (Bi=0.567), grassland savanna (Bi=0.222) and woodland savanna (Bi=0.183) was higher than in other habitats. The species appears to be not common in NPF and Sw. in both national parks. Likewise, SF recorded no GP in DDNP, with the probability to record the species there being very low (Bi=0.025). However, the probability to detect giant pangolin have not differed significantly among habitat types of both park ($p \geq 0.05$; Table XVIII).

Table XVIII: Habitat selection ratio and probability to detect giant pangolin in different habitat types.

Parks	Habitat types	O_i	π_i	Wi	Bi	1/Bi
DDNP	GF	1.93	2.58^d	0.748	0.898	1
	GS	0.19	10.99^c	0.017	0.021	48
	NPF	0	55.5^a	0	0	-
	SF	0.22	31.42^b	0.0 07	0.008	125
	Sw.	0	9.01^c	0	0.000	-
	WS	0.43	7.1^c	0.061	0.073	14
	Value of χ^2	$\chi^2=4.43$	$\chi^2=106.03$	$\chi^2=2.60$	$\chi^2=3.06$	-
	p-value	p=0.35	p=0.0001	p=0.62	p=0.55	-
MDNP	GF	1.04	7.08^d	0.147	0.021	48
	GS	1.3	22^b	0.059	0.226	4
	NPF	0	14^c	0	0	-
	SF	0.24	36.5^a	0.007	0.025	40
	Sl.	-	1.3^e	-	-	-
	Sw.	0	2^e	0	0	
	WS	0.8	16.7^c	0.048	0.183	5
	Value of χ^2	$\chi^2=2.76$	$\chi^2=56.49$	$\chi^2=0.14$	$\chi^2=0.54$	
	p-value	p=0.60	P=0.0001	p=0.99	p=0.96	

1/Bi denotes the numbers of trapping days necessary to record one event. Park codes are DNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. Oi = trapping rate of giant pangolin recorded in 'i' habitat type 'i' and πi the percentage of the habitat 'i' that is available; Wi= selection ratio, Bi= Manly's standardized selection ratio denotes the probability of habitat to be selected. Dashed rows denote habitats where camera traps were not installed.

III.1.2.3.2 Behavior of white-bellied pangolin

White-bellied pangolins were frequently observed exhibiting feeding behavior through activities such as eating (30.81%), foraging (24.71%) and passing (43.6%), and rarely nesting and territorial behavior with individuals observed entering or exiting the burrow (0.58%), and scent marking the territory (0.29%, Fig.34a). Passing activity were significantly higher ($\chi^2=73.08$ df=4; $p<0.0001$) than other activities. The Figure 35 shows different white-bellied pangolins' activities on different placement targets. The different letters on figure 35a denote significant differences of trapping rates.

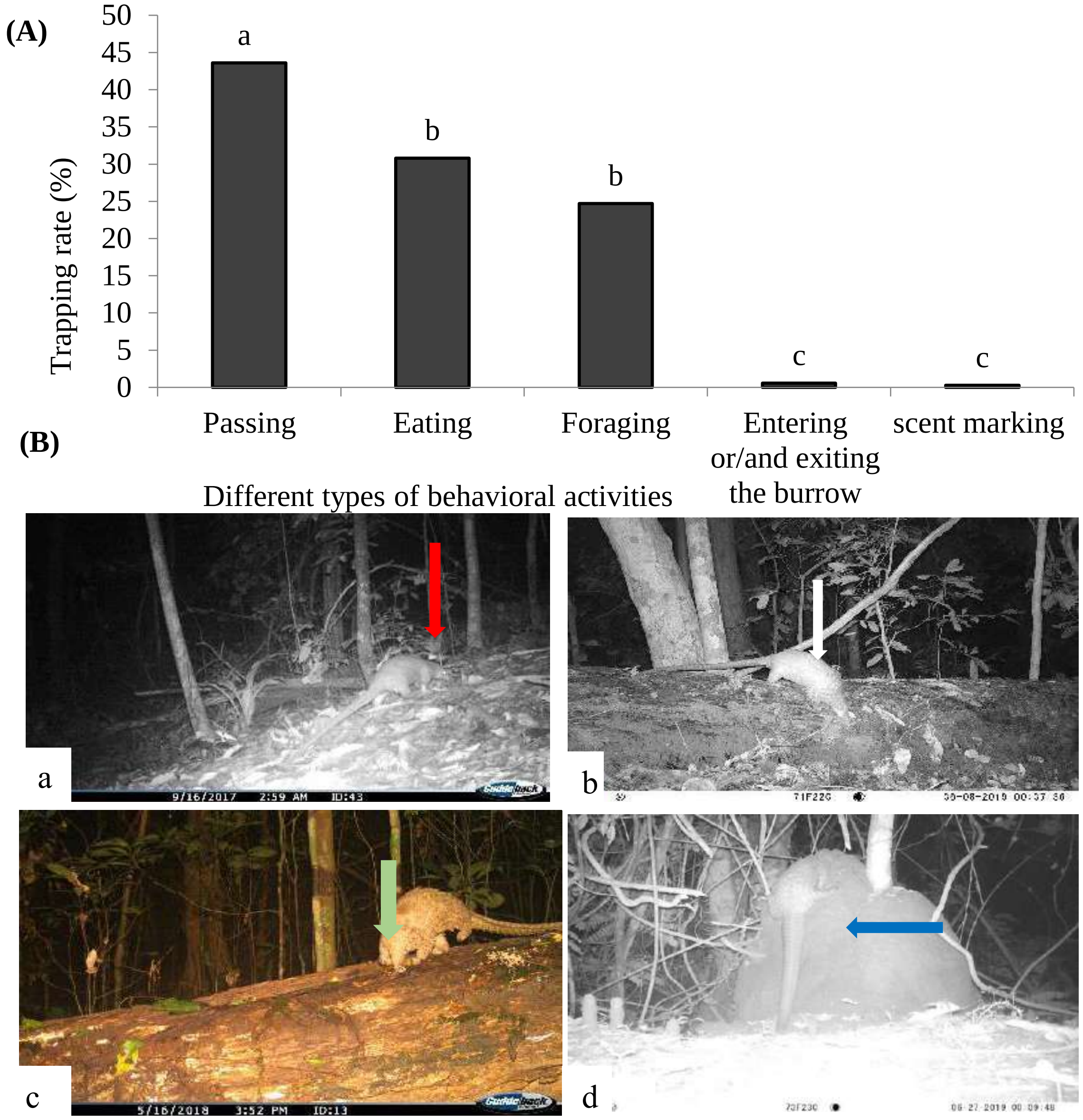


Figure 34: Different type of behavioral activities of white-bellied pangolins observed on photos (A) trapping rates of each activity type; (B) photos illustrating each activity recorded. (a) passing activity on ground; (b) Eating activity on dead fallen log; (c) Eating activity on dead fallen log; (d) Foraging activity on termite mound.

III.1.2.3.2.1 Variation of white-bellied pangolin activity on placement target type

White-bellied pangolin (WBP) eating activity (25.58%; 88 events) was significatively (χ^2=121.81; df=6; p<0.0001) associated with Dead Trunk with Termites (DTWT) than other target types with (4.07%; 14 events) on GFS and (1.45%; 5 events) on FSST (Fig. 35). Similar association was recorded for WBP foraging (13.8%; 45 events) on DTWT, also frequently associated to Ground Feeding Sites (GFS) and Feeding Sites on Standing Trunk (FSST). Pangolin was observed most frequently passing on all target types. Although passing activity was significantly associated with

Living Burrows (LB), Dead Trunk Without Termites (DTWtT), Tree Hollow (TH), and Termite Mound (TM; Fig.36) than other target types. No foraging activity was observed on living burrows (Table XIX). Behavioral activities of WBP had varied significantly (p<0.0001) on DTWtT, GFS and DTWT than other activities. The foraging activity was more frequent on GFS, followed by Eating (4.07%; 14 events) and passing was the most rarely recorded activity. On DTWT eating and passing activities significantly dominated foraging activity, while on DTWtT passing activity significantly dominated other activities. The Figure 35 shows the different activities of WBP on different placement targets.

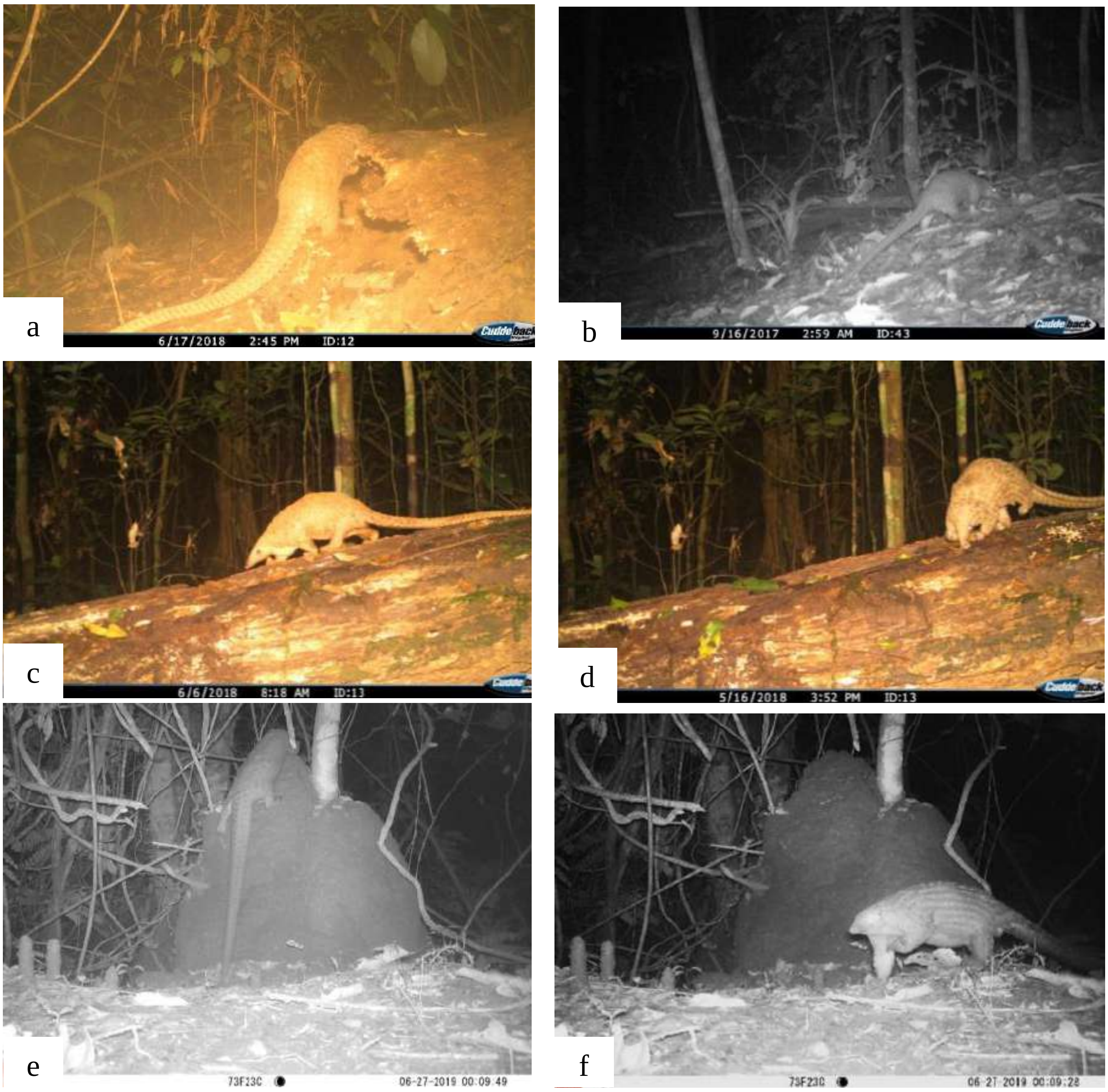


Figure 35: White-bellied pangolin observed activities on each target displaying feeding behavior a) passing near a tree hollow; b) passing on ground feeding site; c) crossing a dead trunk with termites; d) eating on a dead log with termite; e) foraging on a termite mound and f) passing near a termite mound.

The following Table XIX presents variation of trapping rates of white-bellied pangolin behavioral activities observed on different placement targets using camera traps.

Table XIX: Trapping rates of white-bellied pangolin behavioral activities observed on different placement targets

		Placement targets									
		FSST	**GFS**	**LB**	**DTWT**	**DTWtT**	**TM**	**TH**	Value of χ^2	p-value	**Total**
	SE →	1,284	1,854	2,636	2,655	1,092	290	818			10,629
Behavioral activities	Eating	1.45 (5)^{c}	4.07 (14)$^{b/B}$	0 (0)	25.58 (88)$^{a/A}$	0.29 (1)$^{d/C}$	0 (0)	0 (0)	χ^2=121.8	p<0.0001	31.39 (109)^{b}
	Entering and exiting	0 (0)	0 (0)	0.58 (2)	0 (0)	0 (0)	0 (0)	0 (0)	χ^2=3.48	p=0.75	0.58 (2)^{d}
	Foraging	3.2 (11)^{bc}	5.52 (19)$^{b/A}$	0 (0)	13.08 (45)$^{a/B}$	2.03 (7)$^{c/B}$	0.29 (1)^{d}	0.58 (2)^{d}	χ^2=36.61	p<0.0001	24.71 (85)^{b}
	Passing	0.87 (3)^{d}	0.58 (2)$^{d/C}$	2.03 (7)^{c}	21.8 (75)$^{a/A}$	15.12 (52)$^{b/A}$	1.16 (4)^{c}	2.03 (7)^{c}	χ^2=71.16	P<0.0001	43.6 (150)^{a}
	Scent marking	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	χ^2=1.74	P=0.94	0.29 (1)^{d}
	Non categorized	0 (0)	0 (0)	0 (0)	1.25 (5)^{C}	0 (0)	0 (0)	0(0)	χ^2=6.25	p=0.28	1.25 (5)^{c}
	Value of χ^2	χ^2=6.09	χ^2=13.12	χ^2=5.93	χ^2=47.10	χ^2=49.30	χ^2=3.48	χ^2=5.93	-	-	χ^2=73.08
	p-value	p=0.19	p=0.01	p=0.20	p=0.0001	p=0.0001	p=0.48	p=0.20	-	-	p=0.0001
	Total	5.81 (20)^{c}	10.17 (35)^{b}	2.62 (9)^{d}	60.47 (208)^{a}	17.44 (60)^{b}	1.45 (5)^{d}	2.62 (11)^{c}	χ^2=187.5	p=0.0001	3.34 (355)

SE= Sampling Effort; FSST=Feeding site on standing tree; GFS=Ground feeding sites; LB= Living burrow; DTWT=Decaying trunks with termites; DTWtT= Decaying trunks without termites; TM=Termite mound; TH= Tree hollow. The numbers into brackets are the number of independent photographic events recorded. The different low case letters in rows and capital letters in columns indicate significant differences following pairwise comparisons of trapping rates between different placement target types.

Each category of pangolin activities was significantly associated on a specific target. Correspondence analysis (Fig. 36) shows the strength of association of the main observed pangolin activity recorded on each target. The lower the distance value between the target and the activity, the more frequent the activity on the target. In other words, the white-bellied pangolin activity is very important (frequently associated) with the target. Pearson's Chi-square test of the correspondence analysis shows a high significant association ($\chi^2 = 211.68$, df = 4, $p < 0.001$) of passing pangolin activity on TH, TM, DWtT and LB and also Eating activity on DTWT while foraging activity was associated with GFS and FSTT.

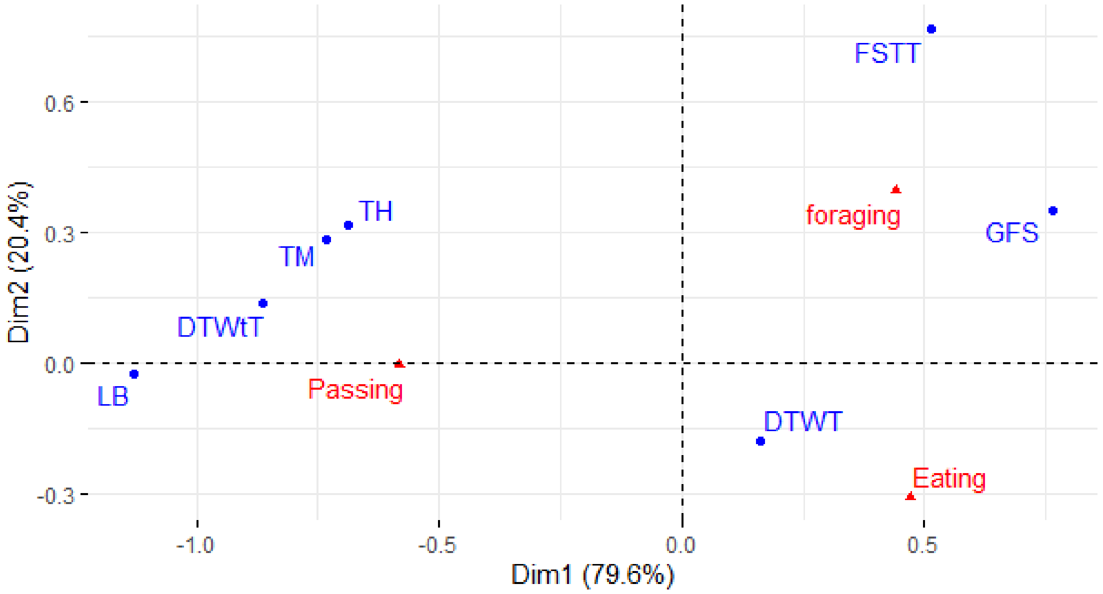


Figure 36: Correspondence Analysis showing activity of white-bellied pangolin individuals associated with different types of targets. Dimension 1 (Dim1) contributes to explaining 79.6% of the variance, and dimension 2 (Dim2) explains 20.4%. The blue circles represent target types, and the red triangles represent each pangolin activity. FSST=Feeding site on a standing tree; GFS=Ground feeding sites; LB= Living burrow; DTWT=Decaying trunks with termites; DTWtT= Decaying trunks without termites; TM=Termite mound; TH= Tree hollow.

III.1.2.3.2.2 Effect of habitat type on pangolin behavioral activity

White-bellied pangolin (WBP) observed eating activities were significantly associated (χ^2=97.02; df=5; p<0.0001) to Secondary Forest (SF) than other habitat types (Fig. 38). Foraging activity was significantly higher (χ^2=107.92; df=5; p<0.0001) in Secondary Forest (27.25%; 109 events) than Near Primary Forest (NPF, 5%; 20 events) and Woodland Savanna (0.5%; 2 events). WBP observed passing events were significantly (χ^2=78.63 df=5; p=0.001) higher in SF (16.25%; 65 events) and in NPF (17.5%; 70 events; Table XX) than other habitat types. Passing activity was more frequently recorded in NPF (17.0%; 68 events) than others behavioral activities with a significant difference (χ^2=57.60; df=5; p<0.0001); followed by foraging and eating activities. While in SF eating activity was significantly (χ^2=100; df=5; p<0.0001) more frequent compare to other activities. These trends are confirmed by the correspondence analysis (Fig. 37).

Table XX: Variation of trapping rate of white-bellied pangolin activities among habitat types

		Habitat types								
		GF	**GS**	**NPF**	**SF**	**Sw.**	**WS**	**Value of χ^2**	**p-value**	**Total**
	SE →	**400**	**1,675**	**766**	**2,448**	**617**	**1,674**			**7,580**
Behavioral activities	Eating	0.25 (1)^{c}	0 (0)	2.5 (10)$^{b/C}$	23.75 (95)$^{a/A}$	0.25(1)$^{c/B}$	0.75 (3)^{c}	χ^2=97.02	p<0.0001	27.25 (109)^{b}
	Entering and exiting	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.5 (2)	χ^2=2.5	p=0.77	0.5 (2)^{e}
	Foraging	0 (0)	0 (0)	5 (20)$^{b/B}$	16.0 (64)$^{a/B}$	0 (0)	0.25 (1)^{c}	χ^2=107.9	p<0.0001	21.25 (85)^{c}
	Passing	0.25 (1)^{c}	0.5 (2)^{c}	17.0 (68)$^{a/A}$	16.25 (65)$^{a/B}$	2.25 (9)$^{b/A}$	1.5 (6)^{b}	χ^2=78.63	P<0.0001	37.5 (150)^{a}
	Scent marking	0 (0)	0 (0)	0 (0)	0.25 (1)^{D}	0 (0)	0 (0)	χ^2=1.25	p=0.94	0.25 (1)^{e}
	Non-identified	0 (0)	0 (0)	0 (0)	1.25 (5)^{C}	0 (0)	0 (0)	χ^2=6.25	p=0.28	1.25 (5)^{d}
	Value of χ^2	χ^2=1.25	χ^2=2.5	χ^2=57.60	χ^2=100	χ^2=15	χ^2=6	-	-	χ^2=158
	p-value	p=0.94	p=0.77	p<0.0001	p<0.0001	p=0.02	p=0.3	-	-	p<0.0001
	Total	0.25 (1)^{d}	0.5 (2)^{d}	24.5 (98)^{b}	57.5 (230)^{a}	2.5 (10)^{c}	3.0 (12)^{c}	χ^2=178.4	p<0.0001	3.34 (355)

SE: Sampling Efforts; GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The numbers into brackets are the number of independent photographic events recorded. The numbers in bold denote the highest trapping rates. The different low case letters in rows and capital letters in columns indicate significant differences following pairwise comparisons of trapping rates between different habitat types.

The Pearson's Chi-square test of the correspondence analysis shows that there was a high significant association type (χ^2 = 211.68, df = 4, p<0.001) of passing activity with near primary forest, while eating and foraging activities were associated on secondary forest. Correspondence analysis (Fig. 37) shows the strength of the association of the main pangolin activity recorded in each habitat type. The low distance values between activity (in blue circles) and habitat type (red triangles) denote the more frequent activities associated with habitat. In other words, the white-bellied pangolin activity occurs more frequently in the habitat. It confirms that the passing activity was significantly associated with NPF than SF and that the foraging activity was more associated with SF than NPF.

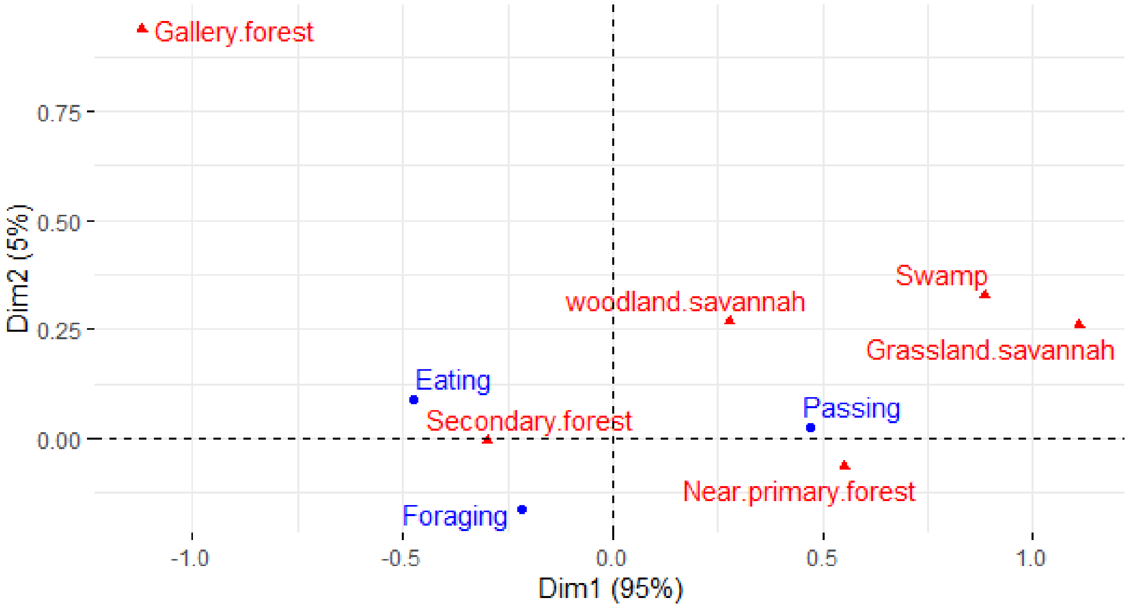


Figure 37: Correspondence analysis showing the different activities of white-bellied pangolins associated with the different types of habitats. Dimension 1 (Dim1) contributes to explain 95% of the variance, and dimension 2 (Dim2) explains 5% suggesting no random association. The blue circles represent each pangolin activity, and the red triangles represent target types.

III.1.2.3.2.3 Seasonal variation of white-bellied pangolin activities

White-bellied pangolin (WBP) was observed feeding more frequently during the rainy season (31.10%; 108 events) compared to the dry season (only one event). WBP feeding activity trapping rate was significantly higher (χ^2=29.19; df=1; p=0.0001) during the rainy season than in the dry season. While foraging activities recorded were significantly lower (χ^2=7.19; df=1; p=0.005) during the rainy (5.81%; 20 events) than the dry season (18.9%; 65 events). WBP passing events recorded have not varied significantly (χ^2=0.94; df=1; p=0.33) between the rainy (25.0%; 86 events) and dry seasons (18.6%; 86 events).

During the rainy season, WBP fed mostly on Ground Feeding Sites (GFS; 3.78%; 13 events), Dead Trunk with Termites (DTWT; 25.58%; 88 events), and rarely on Feeding Sites on Standing Trunk (hereby FSST; 0.87%; 3 events), and Termite Mound (TM; 0.29%; 1 event). They are the same sites where the species forage with a similar frequency of activity. The trapping rate of WBP feeding activity was significantly higher (χ^2=109.89; df=6; p<0.0001) on DTWT than other targets. WBP passed near all targets during the dry season as well as in rainy except GFS (see Table XXI).

The Generalized Linear Models (GLM) results on the WBP activity frequencies show a significant effect of season, target type, and activity type on the trapping rate. The WBP activities were observed more often in the rainy season than the dry season and on the DTWT than other targets. The model that includes only season did not influence the frequency of activities of the WBP. The best models that predicted the WBP frequency of activities include the behavior and target types (the lowest AIC=104.90; Table XXI) followed by season, behavior and target types (AIC=245.56).

Table XXI: Generalized Linear Models showing variation of white-bellied pangolin trapping rates' activities on targets per season.

		Placement targets							
		FSST	**GFS**	**LB**	**DTWT**	**DTWtT**	**TM**	**TH**	**Total**
Dry season	**SE** →	590	898	770	1473	546	26	389	4692
Behavioral activities	Eating	0 (0)	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Entering and exiting	0 (0)	0 (0)	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Foraging	1.74 (6)	4.65 (16)	0 (0)	11.05 (38)	0.87 (3)	0 (0)	0.58 (2)	18.9 (65)
	Passing	0.58 (2)	0.58 (2)	0.87 (3)	15.12 (52)	6.69 (23)	0.29 (1)	0.87 (3)	**25.0 (86)**
	Scent marking	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Total	2.69 (9)	5.52 (19)	1.16 (4)	26.17 (90)	7.56 (26)	0.29 (1)	1.41 (5)	44.77 (154)
Rainy season	**SE** →	694	956	1866	1182	546	264	429	5937
Behavioral activities	Eating	1.45 (5)	3.78 (13)	0 (0)	**25.58 (88)**	0 (0)	0.29 (1)	0 (0)	**31.10 (108)**
	Entering and exiting	0 (0)	0 (0)	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Foraging	1.45 (5)	0.87 (3)	0 (0)	2.03 (7)	1.16 (4)	0.29 (1)	0 (0)	5.81 (20)
	Passing	0.29 (1)	0 (0)	1.16 (4)	**6.69 (23)**	**8.43 (29)**	0.87 (3)	1.16 (4)	**18.6 (64)**
	Scent marking	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Total	3.48 (12)	4.65 (16)	1.45 (5)	34.3 (118)	9.59 (33)	1.45 (5)	1.16 (4)	55.51 (191)

Model factors	***df***	**RD**	**p (χ^2)**	**AIC**
Season	1	3.77	0.05	1269.4
Behaviour	4	328.26	0.00001	950.87
Target	6	335.96	0.00001	947.16
Season*Target	6	61.31	0.00001	896.08
Season*Behaviour	4	239.99	0.00001	409.51
Behaviour*Target	24	163.95	0.00001	104.90
Season*Behaviour* Target	24	30.33	0.17	245.56

SE= Sampling Effort; FSST=Feeding site on standing tree; GFS=Ground feeding sites; LB= Living burrow; DTWT=Decaying trunks with termites; DTWtT= Decaying trunks without termites; TM=Termite mound; TH= Tree hollow. The numbers into brackets are the number of independent photographic events recorded. The grey color denotes the highest trapping rates. *df*=degrees of freedom, RD= residual deviance, *P(χ^2) Chi-square* p-value, AIC= Akaike Information Criterion.

III.1.2.3.2.4 Annual variation of pangolin activity on different targets

The white-bellied pangolin (WBP) eating activity recorded was significantly higher (χ^2=24.95; df=2; p=0.0001) in 2019 (29.07%; 100) than in 2018 (1.45%, 5 events). Only one event showing the eating activity was recorded in 2020. WBP fed on FSST, DTWT, and GFS in 2018 but mostly in 2019, while almost all sites targeted were frequently used by the WBP in 2019 and 2020 for foraging and passing (see Table XXII).

The GLM result on the WBP activity frequencies shows a significant effect of years, target type, and activity type on the trapping rate. The WBP activities were observed more frequently in 2019 and on the DTWT and DTWtT than other targets. The models combining target types and years did not influence the frequency of activities of this species. The best models (with the lowest AIC=486.33; Table XXII) that predicted the WBP frequency of activities included the year, the behavior, and the target types.

Table XXII: Generalized Linear Models showing annual variation of white-bellied pangolins' different type of activities

		FSST	**GFS**	**LB**	**DTWT**	**DTWtT**	**TM**	**TH**	**Total**
2018	**SE** →	**0**	**288**	**1035**	**306**	**65**	**255**	**330**	**2279**
Behavioral activities	Eating	0 (0)	0 (0)	0 (0)	1.45 (5)	0 (0)	0 (0)	0 (0)	1.45 (5)
	Entering and exiting	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Foraging	0 (0)	0 (0)	0 (0)	0.29 (1)	0.87 (3)	0 (0)	0 (0)	1.16 (4)
	Passing	0 (0)	0 (0)	0 (0)	**4.94 (17)**	**6.1 (21)**	0.58 (2)	1.16 (4)	12.79 (44)
	Scent marking	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
2019	**SE** →	713	668	831	876	481	9	99	3677
Behavioral activities	Eating	0.87 (3)	**3.78 (13)**	0 (0)	**24.13 (83)**	0 (0)	0.29 (1)	0 (0)	29.07 (100)
	Entering and exiting	0 (0)	0 (0)	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Foraging	1.45 (5)	1.45 (5)	0 (0)	2.91 (10)	0.29 (1)	0.29 (1)	0 (0)	6.4 (22)
	Passing	0.29 (1)	0 (0)	1.16 (4)	3.49 (12)	2.91 (10)	0.29 (1)	0 (0)	8.14 (28)
	Scent marking	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
2020	**SE** →	571	898	770	1473	546	26	389	4673
Behavioral activities	Eating	0 (0)	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Entering and exiting	0 (0)	0.29 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (1)
	Foraging	1.74 (6)	4.07 (14)	0 (0)	**9.88 (34)**	0.87 (3)	0 (0)	0.58 (2)	17.15 (59)
	Passing	0.58 (2)	0.58 (2)	0.87 (3)	**13.37 (46)**	6.1 (21)	0.29 (1)	0.87 (3)	22.67 (78)
	Scent marking	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Model factors	***df***	**RD**	**p (χ^2)**	**AIC**
Year	1	36.22	0.0001	1384.5
Behaviour	4	317.88	0.0001	1108.9
Target	6	471.65	0.0001	959.10
Year*Target	6	10.51	0.1	926.37
Year*Behaviour	4	64.78	0.0001	616.48
Behaviour*Target	24	155.52	0.0001	576.43
Year*Behaviour* Target	24	13.85	0.94	**486.33**

SE=Sampling Effort; FSST=Feeding site on a standing tree; GFS=Ground feeding sites; LB= Living burrow; DTWT=Decaying trunks with termites; DTWtT= Decaying trunks without termites; TM=Termite mound; TH= Tree hollow; *: Significant difference. The numbers into brackets are the number of independent photographic events recorded. The grey color denotes the highest trapping rates. *d*f=degrees of freedom, RD= residual deviance, $P(\chi^2)$ *Chi-square* p-value, AIC= Akaike Information Criterion.

III.1.2.3.2.5 White-bellied pangolin activity patterns

White-bellied pangolin activities were nocturnal and extend from 7:00 PM to 5:00 AM (Fig. 38a). These activities mostly include foraging, eating, passing, and rarely entering or exiting the burrow and scent marking (with 1 event was precluded from this analysis). The periods of the different activity categories from several individuals overlap over the night with some peaks of events recorded characterizing optimal activity times. Foraging activity usually started at 7:00 PM with very few events (3 events; Fig. 38a) and increased between 9:00 and 10:00 PM (10 events), reaching a peak at 11:00 PM with almost 15 events. The WBP forages until 1:00 AM, while, at 3:00 PM, the foraging activity was rare, with very few events happening at 4:00 PM. The eating activity period started with more events (color blue five events; Fig. 38b) overlapping the passing period (suggesting separation of activity among different individuals of the species or the same individual at different days) showing three pics of activity at 10:00 PM, 00:00 AM, and 3:00 AM.

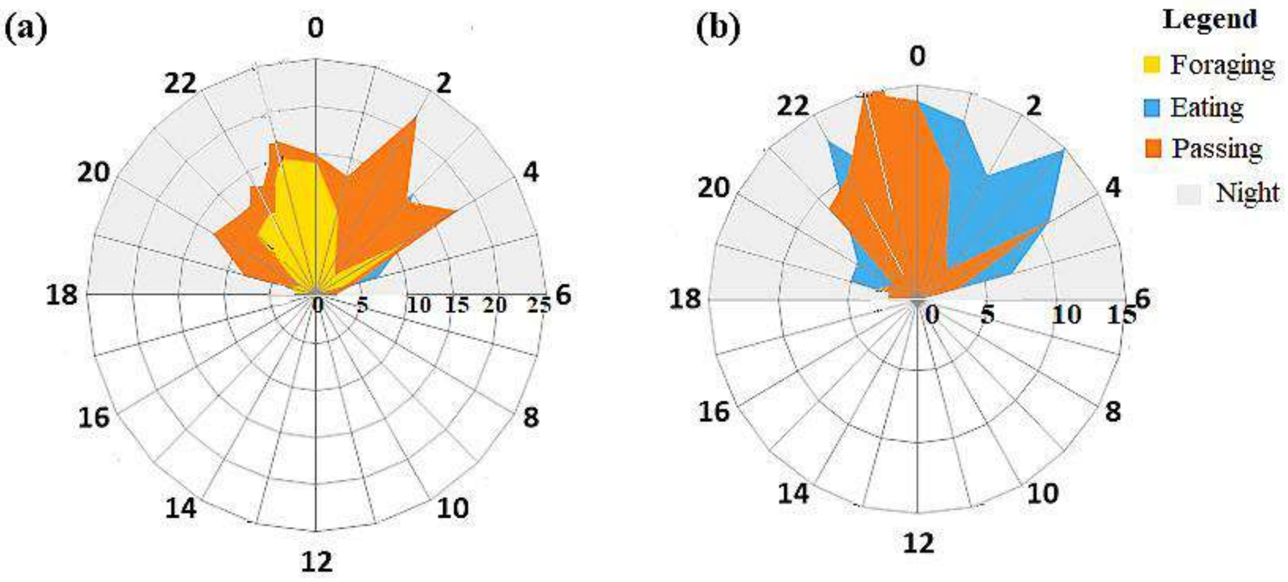


Figure 38: Radial plot showing the overlapping in activity patterns of the White-bellied pangolin (a) all activities overlapping; (b) overlapping between eating and foraging activity periods. The numbers surrounding the circle are hours and those ranging from 0 to 25 on each internal circle are the number of independent photographic event.

Passing activity of white-bellied pangolin (WBP) has started at 7:00 PM and extends till the early morning at 6:00 AM. This trend suggests that different WBP individuals have displayed different activities at different locations and periods. Passing activity recorded four peaks of regular interval after at least 2 hours, respectively at 8:00 PM, 11:00 PM, 2:00 AM, and 4:00 AM (Fig. 39a). No other activity (eating, entering, or exiting the burrow) peaks were recorded simultaneously at the passing period, except foraging, which starts at 6: 00 PM, peaking at 11:00 PM and 4:00 AM (Fig. 39b). Entering or exiting the burrow was rarely observed, with only two events (hidden by the most frequent activity) recorded at 3:00 AM. The foraging activity period was merged in the passing activity period. Based on the radial plot, we can conclude that first, pangolins pass coming from their daily resting places or another foraging sites from 7:00 PM to 9:00 PM. Afterward, foraging activity begins at 9:00 PM and increases until midnight and starts decreasing at 1:00 AM.

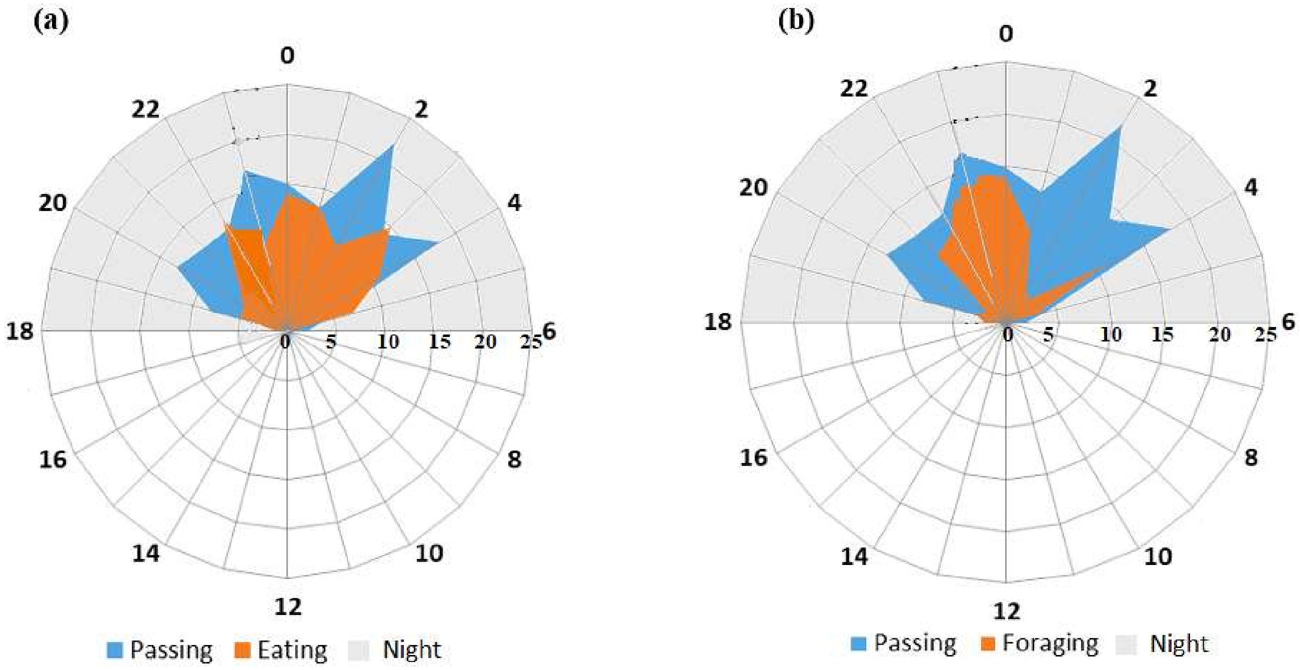


Figure 39: Radial plot showing overlapping between eating and passing activity periods of white-bellied pangolin (a) overlapping between passing activity and eating periods (b) overlapping between foraging activity and passing periods. The numbers surrounding the circle are hours and those ranging from 0 to 5 are the number of independent photographic event.

III.1.2.3.3 White-bellied pangolin habitat selectivity

In both parks, almost all the habitat types were negatively selected (W<0.222; Table XXIII). In the other words, these habitats were not used proportional to their availability. However, in DDNP Near primary forest (Bi=0.344) and swamp (Bi=0.297) have been selected about three times the probability of the other habitat types. In MDNP, the probability to record WBP in SW (0.555; Table XXIII) is higher than in other habitat types. However, the probability to detect white-bellied pangolin have not differed significantly among habitat types of both park ($p \geq 0.05$; Table XXIII). The white-bellied pangolin was not recorded in GS in MDNP and GF in DDNP.

Table XXIII: Habitat selection ratio and probability each habitat to be selected by white-bellied pangolin in different parks.

Parks	Habitat types	Oi	π_i	Wi	Bi	1/Bi
DDNP	GF	0	2.58	0	0	0
	GS	0.19	10.99	0.017	0.027	37
	NPF	12.27	55.5	0.221	**0.344**	**3**
	SF	2.41	31.42	0.077	0.119	8
	Sw.	1.72	9.01	0.191	0.297	3
	WS	0.97	7.1	0.137	0.213	5
	Value of χ^2	$\chi^2=28.08$	$\chi^2=106.03$	$\chi^2=0.40$	$\chi^2=0.60$	
	p-value	p=0.0001	p=0.0001	p=0.99	p=0.98	
MDNP	GF	0	7.0	0	0	0
	GS	0	22	0.000	0.000	-
	NPF	2.58	14	0.184	0.195	5
	SF	5.07	36.5	0.139	0.147	6
	Sl.	-	1.3	-	-	-
	Sw.	1.05	2	0.525	0.555	2
	WS	0.4	16.7	0.024	0.025	40
	Value of χ^2	$\chi^2=9.37$	$\chi^2=56.49$	$\chi^2=1.01$	$\chi^2=1.07$	
	p-value	p=0.05	p=0.0001	p=0.90	p=0.89	

1/Bi denotes the numbers of trapping days necessary to record one event. Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The numbers in bold in the columns denotes the importance of the habitat for white-bellied pangolins. Dashes in rows denote habitat where camera traps were not installed.

III.1.3 Potential insect preys

III.1.3.1 Potential ant prey diversity

Overall, 14,093 ant individuals representing S = 107 species, 29 genera, and six subfamilies were recorded in both protected areas.

III.1.3.1.1 Potential prey species

Subfamilies

Myrmicinae was the most speciose subfamily (41 species, 46.06% of all sampled species; Fig. 40) in DDNP followed by Formicinae (36 species, 40.44%); while in MDNP Formicinae was the most common subfamily (52 species, 51.66%), followed by Myrmicinae (22 species, 36.66%; see Fig. 40). Ponerinae (Lepeletier de Saint-Fargeau, 1835), Dolichoderinae Forel, 1878 and Dorylinae Forel, 1893 were the least common subfamilies, while Cerapachyinae Wheeler, 1902 recorded a single species collected in DDNP. The percentages of species recorded in Myrmicinae and Formicinae subfamilies were significantly higher (χ^2=51.9, df=5, p=0.001) than in other subfamilies.

Genera

The most speciose genera were *Crematogaster* Lund,1831 with 17 species (58.62% of sampled species) in DDNP and 10 species (34.48%) in MDNP, followed by *Tetramorium* Mayr, 1855 with 12 species (41.37%) in DDNP and 9 species (31.03%) in MDNP. Eighteen other genera recorded at least 2 species (6.89%), while 13 genera namely *Axinidris*, *Cerapachys*, *Tapinoma*, *Paraparatrechina*, *Paratrechina*, *Cardiochondyla*, *Carebera*, *Decamorium*, *Myrmicaria*, *Odontomachus*, *Hypoponera*, *Leptogenis*, and *Loboponera* recorded each a single species (which represents 3.45% of sampled species). Figure 40 shows the percentages of ant species in different sub-families recorded in Deng Deng National Park and Mpem et Djim National Park.

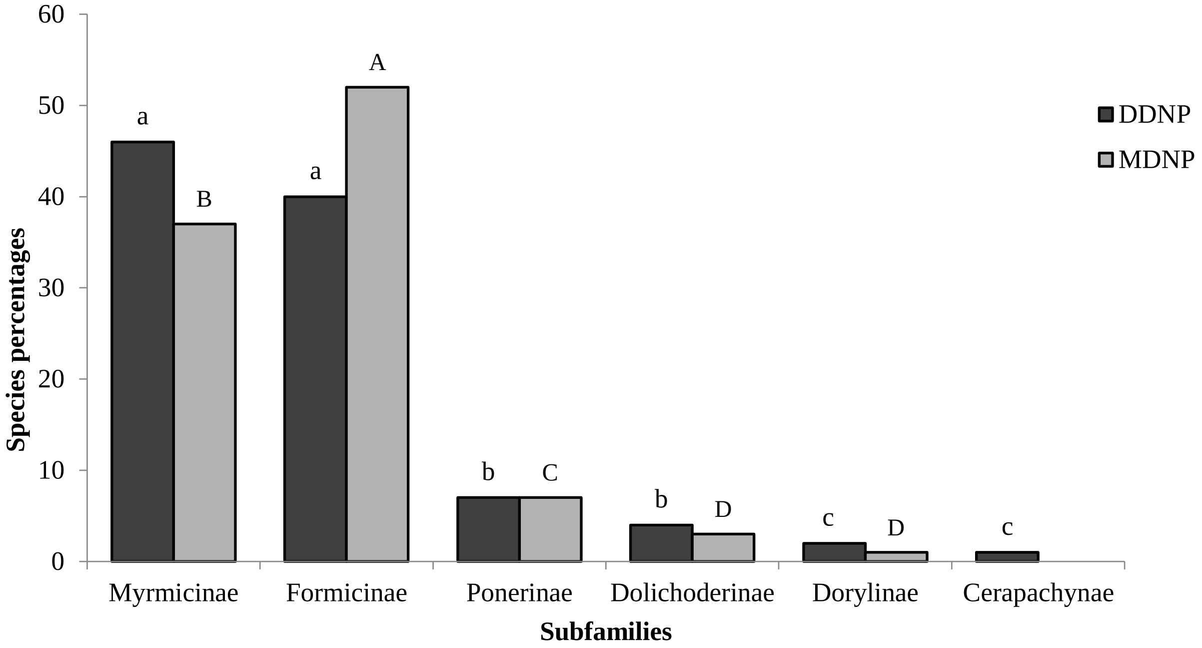


Figure 40: Percentages of ant species in different sub-families recorded in Deng Deng National Park (DDNP) and Mpem et Djim National Park (MDNP). Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species percentage between different parks.

III.1.3.1.1.1 Variation of species percentages between protected areas

In Deng Deng National Park (DDNP), 6,596 ant individuals (46.80% of all sampled individuals) were recorded representing S = 88 species (82.40% of all species identified), 25 genera (86.05%), and six subfamilies (100%). In Mpem et Djm National Park (MDNP), 7,986 individuals (56.66%) were collected, comprising S = 60 species (55.55%), 19 genera (65.51%), and five subfamilies (83.3%). The percentage of ant species was significantly higher (χ^2=5.65, df=1, p<0.01) in DDNP with 89 species compared to 60 in MDNP.

III.1.3.1.1.2 Variation of ant species percentages in different habitat types

The percentage of ant species sampled in DDNP was significantly highest (χ^2=89.88, df=5, p<0.0001) in Near primary Forest (55 species, 56.92%) than in the other habitats; while the secondary forest percentage of ant species significantly dominated (χ^2=41.87, df=5, p<0.0001) in MDNP (41 species, 42.96%) followed by near primary forest (33 species, 30.55%; Fig. 41). Swamps were sampled only in DDNP and have the lowest percentage of species.

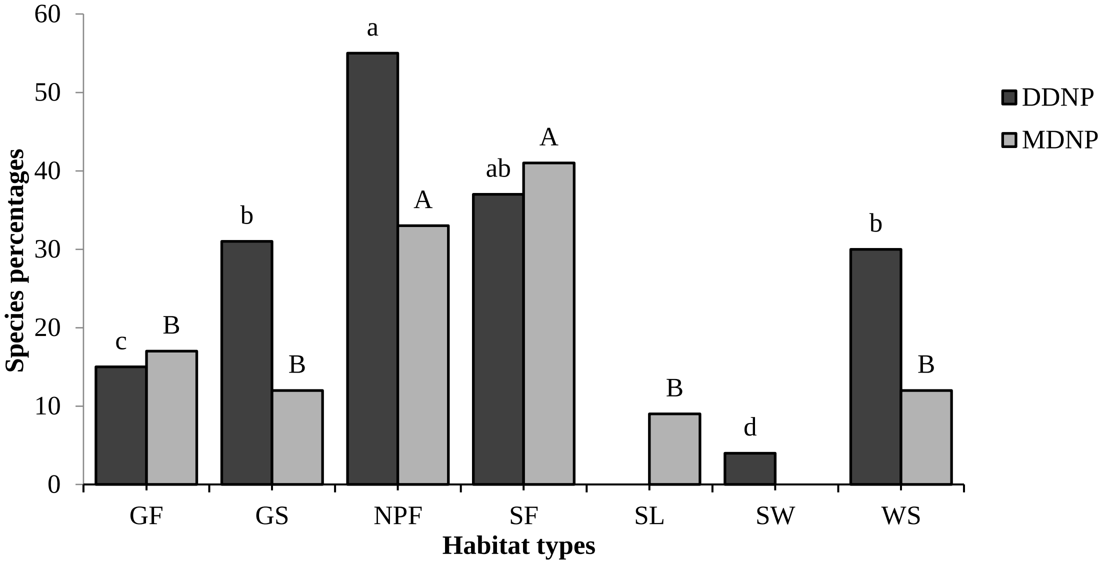


Figure 41: Percentages of ant species in different habitats recorded in Deng Deng National Park (DDNP) and Mpem et Djim National Park (MDNP). Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species richness between different habitat types in different parks.

III.1.3.1.1.3 Seasonal variation of ant species percentages

Overall, the percentage of ant species sampled in Deng Deng National Park (DDNP) had no significant difference (χ^2=3.12, df=1, p=0.08) during the dry and rainy seasons, the same at Mpem et Djim National Park (MDNP) (χ^2=1.57, df=1, p=0.21).

In DDNP, near primary forest ant species percentage was significantly highest (χ^2=4.27, df=1, p=0.03) in the dry season than other habitats except SF in rainy season (Fig. 42a). Other habitats species percentages were non-significantly different between the rainy and dry seasons ($p \geq 0.05$); woodland savanna recorded the same number of species in both seasons. In MDNP, Secondary forest ant species percentage was significantly highest (χ^2=14.08, df=1, p=0.0001) in the dry season than other habitats. Near primary forest ant species percentage was higher in the dry season but no significant difference among seasons (χ^2=2.5, df=1, p=0.11). Figure 42 shows ant species percentage in different habitats of each protected area.

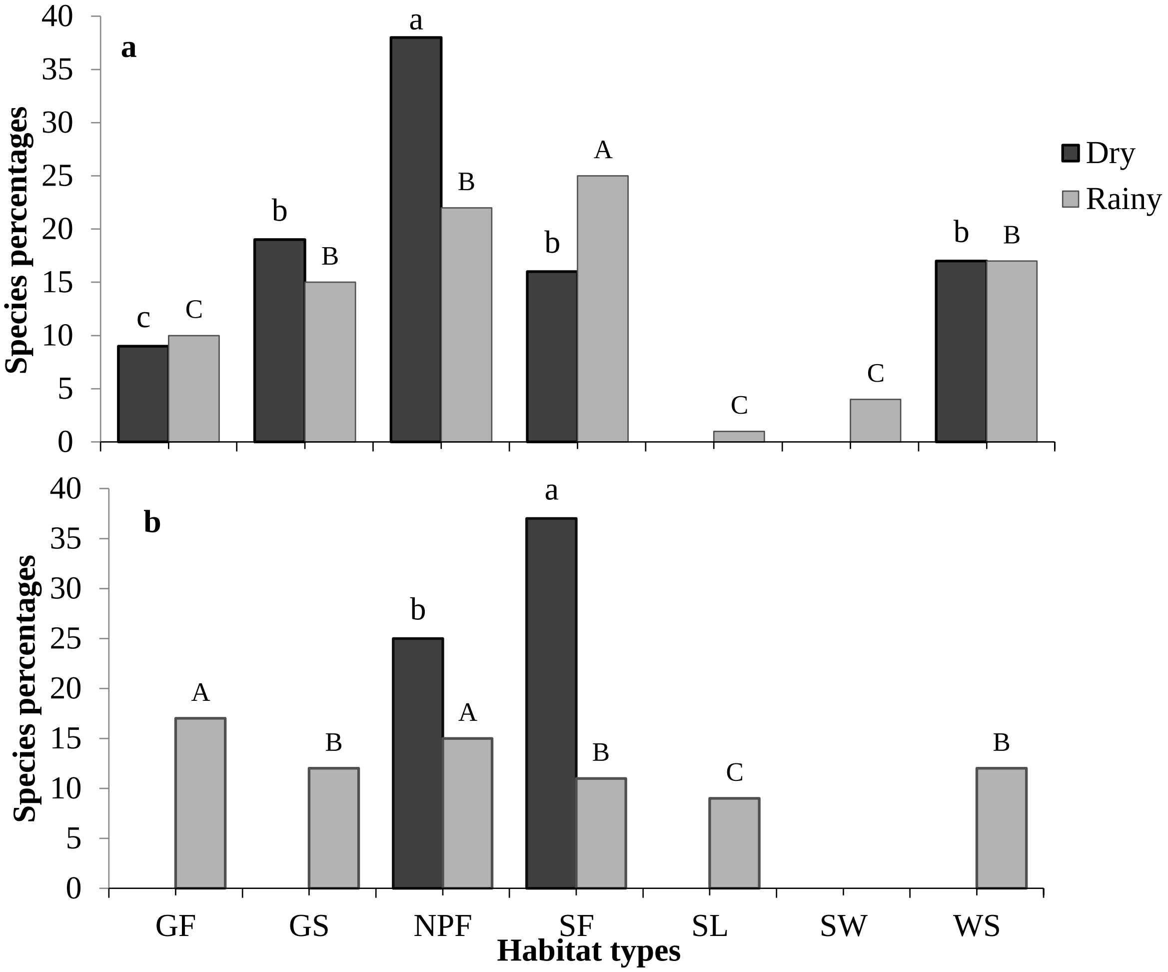


Figure 42: Percentages of ant species sampled in different habitats of each protected area (a) Deng Deng National Park (DDNP) and (b) Mpem et Djim National Park (MDNP). GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The savanna habitats (GF, GS, Sl., and WS) were not sampled in MDNP during the dry season and are not in the seasonal comparison. Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species percentage between seasons in different habitat types in different parks.

III.1.3.1.1.4 Estimators of species richness and ant sampling success

Overall, the sampling success means were 78.05% in Deng-Deng National Park (DDNP) and 86.77% in Mpem et Djim National Park (MDNP; Table XXIV) indicating that for these parks, 21.85% and 13.33%of ant species respectively, remain unidentified.

III.1.3.1.1.4.1 Estimators of species richness and sampling success per parks

In DDNP, Jack 1 has the lower sampling success (68.46%) and Jack 2 the highest sampling success (82.54%) meaning a maximum of 26.7% and a minimum of 18.46% of species are unsampled. In MDNP, if three estimators Chao 2, ICE and Jack revealed 100% of species sampled (that is not true), in fact Jack 2 shown that 11.77% was unsampled. The means of four estimators showed that 86.77% of species are sampled (see Table XXIV) indicating that 13.23% in MDNP are unsampled.

Table XXIV: Species richness and sampling success from species richness estimators by protected areas

	Parks	
Estimators	**DDNP**	**MDNP**
S_{obs}	88	60
ICE	161 (73.06)	60 (100)
Chao 2	146 (76.71)	60 (100)
Jack 1	130 (68.46)	60 (100)
Jack 2	158 (82.54)	68 (88.23)
Means	129.5 (78.05)	58.75 (86.77)

MDNP: Mpem et Dim National Park; DDNP: Deng Deng National Park; S_{obs}: Observed Species richness. The numbers out of brackets are theoretical species richness and those in brackets are the sampling success in percent.

III.1.3.1.1.4.2 Estimators of species richness and sampling success per habitats

Ant sampling success means varied from 61.07% in Near Primary Forest (NPF) to 81.57% in Saltwork (Sl.), and denote that 38.93% and 18.43% of species remain unidentified. No asymptote was approached on rarefaction curves (Fig. 43). More samples are needed to record all the ant species of these habitat types.

Overall, Jack 2 in Gallery Forest (GF) and Grassland Savanna (GS) had the lower sampling success denoting that 35.0% of species are unsampled. Then Chao 2 in Swamp and saltwork, Woodland Savanna (WS), in GF, and GS, and Jack 1 in NPF and SF had the highest sampling success denoting that almost 72 % of ant species of these habitat types were recorded and that a minimum of 35% and a maximum of 48% of ant species remains unidentified in these habitat types (Table XXV).

Table XXV: Estimators of species richness in the different habitat types

	Habitat types						
Estimators	**GF**	**GS**	**NPF**	**SF**	**Sl.**	**Sw.**	**WS**
S_{obs}	26	26	70	61	10	4	37
ICE	36 (72.22)	36 (72.22)	132 (53.03)	96 (63.54)	13 (76.92)	7 (57.14)	62 (59.68)
Chao 2	34 (76.47)	34 (76.47)	175 (40)	105 (58.1)	11 (90.91)	4 (100)	71 (52.11)
Jack 1	35 (74.29)	35 (74.29)	105 (66.67)	86 (70.93)	13 (76.92)	5 (80)	53 (69.81)
Jack 2	40 (65)	40 (65)	134 (52.24)	104 (58.65)	13 (76.92)	6 (66.67)	65 (56.92)
Means	33.875 (77.32)	33.87 (77.32)	120.37 (61.07)	85.86 (72.63)	12.87 (81.57)	5.25 (78.81)	53.875 (70.98)

S_{obs}: Observed Species richness GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. S= Species richness. The numbers out of brackets are theoretical species richness and those in brackets are the sampling success in percent.

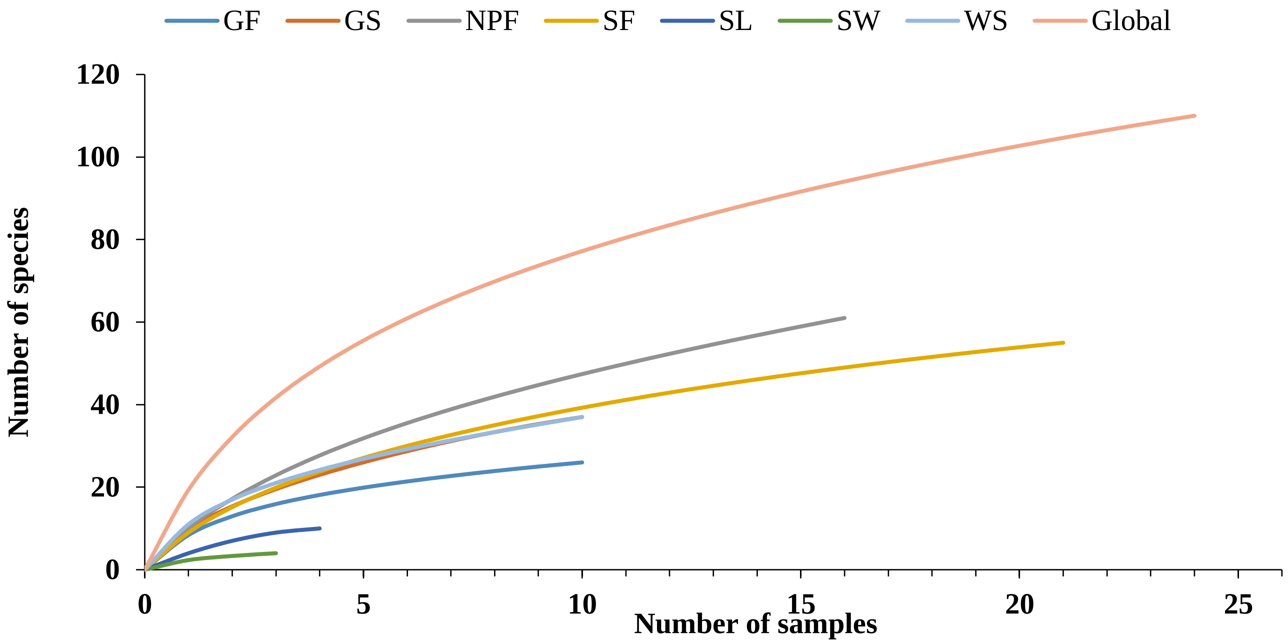


Figure 43: Sample rarefaction (Mao's tau) curves of ants in the different habitat types of the surveyed area and overall sampling. GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp

III.1.3.1.2 Means abundance of ants

III.1.3.1.2.1 Variation of ant abundance between protected areas

Ant abundance mean in Deng-Deng National Park (DDNP) (59.96 ±14.17) was lower than in Mpem et Djim National Park (MDNP; 138.15±67.69). Wilcoxon-Mann-Whitney test suggests a significant difference (U=4992; p=0.02) between both national park ant abundance means.

III.1.3.1.2.2 Variation of ant abundance in different habitat types

In Deng-Deng National Park (DDNP), the ant mean abundance was highest in the secondary forest (23,45±6,33) followed by the near the primary forest (22.65±7.04). The swamp had the lower ant mean abundance (0.55±0.46). The ant means abundance were significantly higher (H=59.75; p<0.00001) in DDNP SF and NPF than the other habitat types. A similar trend was observed in Mpem et Djim National Park (MDNP's) near primary forest (21.95±11.04) and secondary forest (30.10±9.14) followed by gallery forest (9.54±5.31). The saltwork had the lower ant mean abundance (1.49±0.67). In MDNP, NPF and SF ant means abundance were significantly higher (H=23.24; p=<0.00001) than in other habitats (see Table XXVI).

Table XXVI: Ant absolute and average abundance of ants per habitat type in each national park.

Habitat types	Parks	
	DDNP	MDNP
Gallery Forest (GF)	324 (2.95±1.35)^{c}	1050 (9.54±5.31)^{b}
Grassland Savanna (GS)	527 (4.79±1.65)^{b}	657 (5.97±2.92)^{bc}
Near Primary Forest (NPF)	**22396 (22.65±7.04)^{a}**	**2415 (21.95±11.04)^{a}**
Secondary Forest (SF)	**2507 (23.45±6.33)^{a}**	**3311 (30.10±9.14)^{a}**
Swamp (Sw.)	61 (0.55±0.46)^{d}	442 (4.18±1.68)^{b}
Saltwork (Sl.)	-	164 (1.49±0.67)^{d}
Woodland Savanna (WS)	589 (5.35±1.61)^{b}	587 (5.38±1.62)^{c}
Kruskal-Wallis test	H=59.75	H=23.24
P-value	p<0.0001	p=<0.0001

(Mean ± standard error (Standard Error)). Parks codes are: MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park. The numbers in brackets indicate the mean values of the ant abundance. The different letters at the mean values in columns indicate significant differences following pairwise comparisons of different abundance means between habitat types.

III.1.3.1.3 Diversity indices

III.1.3.1.3.1 Variation of ant diversity by park

The ant diversity was significantly (U= 3.0, df=1, p=0.003) higher in DDNP [H' = 3.16; J = 0.76; H'max = 4.49] than in MDNP [H' = 2.24; J = 0.55; H'max = 4.09, Table XXVII]. No species dominates the ant community sampled in DDNP (Berger-Parker dominance index [ID<0.13]). However, a few species were more significantly (H=28.31; p<0.0001) dominant in the swamp (ID=0.47) in MDNP

Table XXVII: variation of ant diversity indices by national park

Parameters	Parks		MWt	p-value
	DDNP	MDNP		
S_{obs}	88	60		
Individuals	6596	15196		
Shannon-Weaver_H	**3.16 (1.13 ±0.06)^{a}**	2.24 (0.87±0.05)^{b}	U =3.0	p=0.003
Pielou Equitability_J	0.76 (0.64 ±0.03)^{a}	0.55 (0.55 ±0.03)^{b}	U =2.15	p=0.03
Berger-Parker_ID	0.13 (0.53 ±0.03)^{b}	0.47 (0.65 ±0.02)^{a}	U =3.55	p=0.008

S_{obs}= Observed Species richness; Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park, MWt= Mann-Whitney test. The numbers in parentheses indicate the mean values of the parameters. The different letters in rows indicate significant differences following pairwise comparisons of different parameter means between national parks.

III.1.3.1.3.2 Effect of habitat type on ant diversity

Secondary forest (SF) was highly diversified (H’=2.74 [0.63±0.04); E=0.76 (0.15±0.08)] in Deng-Deng National Park (DDNP) and (H’=2.35 [(0.8±0.11); E=0.63 (0.46±0.06)] in Mpem et Djim National Park (MDNP) followed by the NPF, WS, GF, and GS while the swamp (H’=0.47 [0.48±0.08], E=0.44 [0.65±0.07]) and saltwork (H’=1.08 [0.82±0.29]; E= 0.78 [0.74±0.06]) habitats were poorly diversified. Ant was significantly diversified (H=43.18; p<0.0001) in DDNP’s SF than other habitats. The same statistical result (H=11.63; p=0.017) was found for Pielou Equitability. No species dominates the ant community sampled in GS, WS, GF, NPF, and SF in DDNP (Berger-Parker dominance index [ID<0.40]). However, a few species were more significantly (H=28.31; p<0.0001) dominant in the swamp (ID=0.87; Table XXVIII) in DDNP.

Table XXVIII: Averages of ant diversity indices per habitat type in Deng Deng National Park

	Habitat types							
P	**GF**	**GS**	**NPF**	**SF**	**Sw.**	**WS**	**Test**	**p-value**
S_{obs}	15	31	55	37	4	30		
I	324	527	2492	2580	61	589		
H	1.88 (0.21±0.05)^{b}	2.51 (0.23±0.06)^{b}	2.64 (0.22±0.06)^{b}	2.74 (0.63±0.04)^{a}	0.62 (0.03±0.02)^{c}	2.63 (0.22±0.06)^{b}	H=43.18	p<0.0001
E	0.69 (0.58±0.1)^{b}	0.73 (0.57±0.1)^{b}	0.66 (0.60±0.08)^{a}	0.76 (0.15±0.08)^{c}	0.44 (0.49±0.1)^{b}	0.42 (0.19±0.08)^{c}	H=11.63	p=0.017
ID	0.39 (0.22±0.06)^{c}	0.25 (0.19±0.05)^{c}	0.19 (0.31±0.07)^{b}	0.12 (0.5±0.04)^{a}	0.82 (0.09±0.05)^{d}	0.2 (0.2±0.06)^{c}	H=28.31	p<0.0001

P= Parameters; S_{obs}: Observed Species richness; I= individuals, H= Shannon-Weawer; E= Pielou Equitability; ID=Berger-Parker. Averages are presented as follows [global indices value (Mean index ± Standard Error)]. Test= Kruskal-Wallis test Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; GS=Grassland Savanna; Sw.= Swamp. The different letters at the mean values indicate significant differences

In Mpem et Djim National Park (MDNP), SF (H’=2.35 [(0.8±0.11)]; J=0.63 [(0.46±0.06)] was significantly (H=11.36; p=0.02) more diversified than NPF (H’=1.22 [(0.29±0.08); J=0.35 [0.21±0.06)]) and other habitat types. Few numbers of species have dominated significantly (H=28.31; p<0.0001) in NPF’s MDNP [ID=0.69 (0.29±0.08)]; Table XXIX). Ant diversity was significantly lower (p<0.001) in swamps and saltworks than in the other habitats.

Table XXIX: Averages of ant diversity indices per habitat type in Mpem et Djim National Park.

	Habitat types							
Parameters	GF	GS	NPF	SF	Sl.	WS	Test	p-value
$\boldsymbol{S_{obs}}$	17	12	33	41	9	12		
Individuals	1092	657	7682	5157	164	444		
Shannon- Weaver _H	1.67 (0.34±0.1)^{b}	1.86 (0.39±0.11)^{b}	1.22 (0.29±0.09)^{c}	2.35 (0.8±0.11)^{a}	1.74 (0.44±0.12)^{b}	1.98 (0.4±0.11)^{b}	H=11.36	p=0.02
Pielou Equitability_E	0.59 (0.25±0.07)^{b}	0.75 (0.27±0.07)^{b}	0.35 (0.21±0.06)^{c}	0.63 (0.46±0.06)^{a}	0.79 (0.23±0.06)^{b}	0.80 (0.27±0.07)^{b}	H=8.39	p=0.07
Berger-Parker_ID	0.49 (0.25±0.07)^{b}	0.45 (0.24±0.07)^{b}	0.69 (0.29±0.08)^{b}	0.36 (0.69±0.04)^{a}	0.34 (0.27±0.07)^{b}	0.31 (0.25±0.06)^{b}	H=26.8	p=0.0001

S_{obs}= Observed Species richness. Averages are presented as follows [global index value (Mean index ± Standard Error)]. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna. Test = Kruskal-Wallis test. The numbers in brackets indicate the mean values of the diversity indices. The different letters at the mean values indicate significant differences following pairwise comparisons of different parameters between habitat types.

III.1.3.1.3.3 Seasonal variation of ant diversity

In Deng-Deng National Park (DDNP), the rainy seasons’ ant community was more diversified (H’=2.88; E=0.77) than dry season. There was not significant difference between ant community in both seasons ($p \geq 0.05$). In Mpem et Djim National Park (MDNP), the rainy seasons’ ant community was significantly more diversified (H’=2.41; E=0.069; p=0.001) than in dry season. Except for the ant community in MDNP, where few species were dominant in the dry season (ID=0.66), no species dominates the other ant community sampled in the dry and rainy seasons in both parks (Berger-Parker dominance index [ID<0.30]) (see Table XXX).

Table XXX: Seasonal variation of ant diversity indices in Mpem et Djim National Park and Deng Deng National Park.

Parks	**Parameters**	**Seasons**		Test	p-value
		Dry	**Rainy**		
DDNP	S_{obs}	61	43	-	-
	Shannon-Weaver_H	2.46 (0.87±0.05)^{a}	2.88 (0.98±0.11)^{a}	U =23.0	p=0.053
	Pielou Equitability_E	0.6 (0.51 ±0.03)^{b}	0.77 (0.62 ±0.03)^{a}	U =2.15	p=0.03
	Berger-Parker_ID	0.25 (0.20 ±0.10)^{a}	0.16 (0.20 ±0.16)^{a}	U =39.55	p=0.058
MDNP	S_{obs}	33	45	-	-
	Shannon-Weaver_H	1.52 (0.62±0.02)^{a}	2.41 (0.87±0.17)^{b}	U =4.10	p=0.001
	Pielou Equitability_E	0.4 (0.38 ±0.08)^{b}	0.69 (0.69 ±0.01)^{a}	U =3.15	p=0.011
	Berger-Parker_ID	0.66 (0.65 ±0.02)^{a}	0.25 (0.20 ±0.02)^{b}	U =3.55	p=0.008

S_{obs}= Observed Species richness; Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park. Test=Mann-Whitney U test. The numbers in brackets indicate the mean values of diversity indices. The different letters at the mean values indicate significant differences following pairwise comparisons of different parameters between dry and rainy seasons.

III.1.3.1.4 Variation of ants’ frequency of occurrence

Overall, Myrmicinae, Formicinae, and Ponerinae were the most commonly (Fo>86%) sampled subfamily while Cerapachyinae and Dolyrinae were uncommon (Fo<10). *Palthothyreus* and *Camponotus* were the most commonly sampled genera with *Palthothyreus tarsatus* Fabricius, 1798, *Camponotus brutus* Forel, 1886 and *Camponotus maculatus* Fabricius, 1783 being the most common species.

III.1.3.1.4.1 Variation between protected areas

III.1.3.1.4.1.1 Occurrence of ant subfamilies

At the park level, Formicinae, Ponerinae and Myrmicinae subfamilies were commonly sampled in MDNP (Fo>85%) and DDNP (Fo>50%) respectively. Cerapachyinae and Dolyrinae were less common (Fo<10) in both parks.

III.1.3.1.4.1.2 Occurrence of ant species

Overall, 13 species were commonly sampled in Deng-Deng National Park (DDNP's) ant community with Fo>50%, namely *Tapinoma melanocephalum* (Fabricius, 1793), *Technomyrmex* sp.1, *Camponotus acvapimensis* Mayr, 1862, *Camponotus brutus* Forel, 1886, *Camponotus maculatus* Fabricius, 1783, *Polyrachis decemdentata* André, 1889, *Pheidole megacephala* (Fabricius, 1793), *Pheidole* sp.1, *Pheidole* sp.2, *Crematogaster* sp.3, *Tetramorium aculeatum* (Mayr, 1886), *Tetramorium guineensis* (Bernard, 1953), and *Paltothyreus tarsatus* Fabricius, 1798. Eleven species were commonly sampled in Mpem et Djim National Park (MDNP's) ant community, including *Technomyrmex* sp.1, *Camponotus acvapimensis* Mayr, 1862, *Camponotus brutus* Forel, 1886, *Camponotus maculatus* Fabricius, 1783, *Camponotus pompeius* Forel, 1882, *Crematogaster* (*Sphaerocrema*) sp.2, *Pheidole magri*, *Polyrachis militaris* (Fabricius, 1782), *Tetramorium aculeatum* (Mayr, 1886), *Odontomachus troglodytes* Santschi, 1914 and *Paltothyreus tarsatus* Fabricius, 1798.

Four common ant species were shared between both parks, including *Technomyrmex* sp.1, *Camponotus acvapimensis*, *Camponotus brutus*, *Paltothyreus tarsatus*. Thus, three species occurred preferentially in MDNP namely *C. pompeius*, *Po. militaris*, *Od. troglodytes*, while eight were mainly occurring in DDNP namely *Ta. melanocephalum, Polyrachis decemdetata, Pheidole megacephala, Pheidole* sp.1, *Pheidole* sp.2, *Crematogaster* sp.3, *Tetramorium guineensis.*

Twenty-nine species were less commonly sampled (25%≤Fo<50%) in Deng-Deng National Park (DDNP) ant community, including *Technomyrmex* sp.2, *Dorylus braunsi* Emery, 1895, *Dorylus nigricans* Illiger, 1802, *Camponotus flavomaginatus* Mayr, 1862, *Camponotus* sp.2, *Lepisiota conarda* Santshi, 1930, *Lepisiota* sp., *Polyrachis militaris* (Fabricius, 1782) [being common in Mpem et Djim National Park (MDNP)], *Carebera* sp., *Cataulacus weissi*, *Pheidole minima* Mayr, 1901, *Pheidole* sp.3, *Crematogaster conarda* Emery, 1899, *Crematogaster* (*Sphaerocrema*) sp.1, *Crematogaster acis*, *Crematogaster bequaerti* Forel, 1913, *Crematogaster fauconneti*, *Crematogaster rugosa* André, 1895, *Crematogaster* sp.1, *Crematogaster* sp.4, *Tetramorium anguilinode* Santschi, 1910, *Tetramorium bicarinatum* (Nylander, 1846), *Tetramorium brevispinosum* (Stitz, 1910), *Tetramorium rugosum* Taylor, 2007, *Tetramorium* sp.1, *Anochetus bequarti*, and *Odontomachus troglodytes* Santschi, 1914. 20 species recorded in MDNP's ant community were less common, including *Tapinoma melanocephalum* (Fabricius 1793) (being also less common in DDNP), *Anoplolepis carinata* (Emery, 1899), *Anoplolepis tenella* (Santschi, 1911) , *Camponotus conradti* Forel, 1914, *Camponotus foraminosus* Forel, 1897, *Leptogenis vindicis* Bolton, 1975, *Pheidole albidula* Santschi, 1928, *Pheidole megacephala* (Fabricius, 1793), *Pheidole mentita* Santschi, 1914, *Pheidole* sp.1, *Crematogaster* (*Sphaerocrema*) sp.1, *Crematogaster acis*, *Crematogaster* sp.1, *Crematogaster striatula* Emery, 1892, *Tetramorium brevispinosum* (Stitz, 1910), *Tetramorium gabonense* (André, 1892), *Tetramorium* sp.1 and *Dorylus nigricans* Illiger, 1802, *Camponotus flavomaginatus* Mayr, 1862, and *Lepisiota 118onarda* Santshi, 1930. These three last species were less commonly collected in both national parks.

A total of 47 species recorded in the Deng-Deng National Park (DDNP) and 29 in Mpem et Djim National Park (MDNP) were considered to be rarely or uncommonly sampled in ant communities investigated (Fo <25%; see Table XXXI).

Table XXXI: Frequency of occurrence of ant species sampled in each national park

Subfamilies	Genera	Species	Parks	
			DDNP	**MDNP**
		Number of samples	**480**	**360**
Cerapachynae Wheeler, 1902	*Cerapachys* (1)	*Cerapachys foreli* Smith, 1857	14.29	0
Dolichoderinae Forel, 1878	*Axinidris* (1)	*Axinidris murialae* Shattuck, 1991	14.29	0
	Tapinoma (1)	*Tapinoma melanocephalum* (Fabricius 1793)	71.43	28.57
	Technomyrmex (2)	*Technomyrmex* sp.1	57.14	57.14
		Technomyrmex sp.2	42.86	14.29
Dorylinae Forel, 1893	*Dorylus* (2)	*Dorylus braunsi* Emery, 1895	28.57	
		Dorylus nigricans Illiger, 1802	42.86	28.57
Formicinae Wheeler, 1920	*Anoplolepis* (3)	*Anoplolepis carinata* (Emery, 1899)	14.29	28.57
		Anoplolepis sp.	14.29	0
		Anoplolepis tenella (Santschi, 1911)	14.29	28.57
	Camponotus (14)	*Camponotus vividus* (Smith, 1858)	0	14.29
		Camponotus acvapimensis Mayr, 1862	57.14	85.71
		Camponotus brutus Forel, 1886	100	85.71
		Camponotus chrysurus Gertacker, 1871	0	14.29
		Camponotus congolensis Wheeler, 1922	14.29	0
		Camponotus conradti Forel, 1914	0	28.57
		Camponotus flavomaginatus Mayr, 1862	28.57	28,57
		Camponotus foraminosus Forel, 1897	14.29	28.57
		Camponotus maculatus Fabricius, 1783	100	85.71
		Camponotus pompeius Forel, 1882	0	71.43
		Camponotus sp.1	14.29	0
		Camponotus sp.2	42.86	0
		Camponotus sp.3	14.29	0
		Camponotus sp.4	14.29	0
	Lepisiota (9)	*Lepisiota capensis* (Mayr, 1862)	14.29	14.29

		Lepisiota foreli (Arnold, 1920)	14.29	0
		Lepisiota guineensis (Mayr)	0	14.29
		Lepisiota monardi Santshi, 1930	28.57	28.57
		Lepisiota n sp Cameroun FK	0	14.29
		Lepisiota negrisetosa	14.29	0
		Lepisiota nganguela Santshi, 1937	14.29	0
		Lepisiota sp.	28.57	0
		Lepisiota spinosior (Forel, 1930)	14.29	0
	Oecophylla (2)	*Oecophylla longinoda* (Latreille, 1802)	14.29	14.29
	Paraparatrechina (1)	*Paraparatrechina brunnella* LaPolla & Cheng, 2010	14.29	0
	Paratrechina (1)	*Paratrechina concinnata* LaPolla & Cheng, 2010	0	14.29
	Plagiolepis (1)	*Plagiolepis* sp.	14.29	0
	Polyrachis (2)	*Polyrachis decemdentata* André, 1889	57.14	14.29
		Polyrachis militaris (Fabricius, 1782)	42.86	85.71
			54	81.28
Myrmicinae (Lepeletier -Fargeau, 1835)	*Cardiochondyla* (1)	*Cardiochondyla wassmani* Santschi, 1926	14.29	0
	Carebera (1)	*Carebera* sp.	28.57	0
	Cataulacus (2)	*Cataulacus guineensis* Smith, 1853	0	14.29
		Cataulacus weissi Santschi, 1913	28.57	0
	Decamorium (1)	*Decamorium uelense* (Santschi, 1923)	14.29	0
	Monomorium (3)	*Monomorium borlei* Santschi, 1937	14.29	0
		Monomorium mayri Forel, 1902	14.29	0
		Monomorium sp.	14.29	0
	Myrmicaria (1)	*Myrmicaria opaciventris* Emery, 1893	14.29	0
	Pheidole (12)	*Pheidole albidula* Santschi, 1928	14.29	28.57
		Pheidole concinna Wheeler, 1928	14.29	0
		Pheidole magri Forel, 1910	0	57.14
		Pheidole megacephala (Fabricius, 1793)	57.14	28.57
		Pheidole mentita Santschi, 1914	14.29	28.57
		Pheidole minima Mayr, 1901	28.57	0
		Pheidole pulchella Santschi, 1910	14.29	14.29
		Pheidole rohani Santschi, 1925	14,29	14.29
		Pheidole sp.1	85.71	28.57
		Pheidole sp.2	57.14	14.29

		Pheidole sp.3	28.57	0
		Pheidole speculifera Emery, 1877	14.29	14.29
	Crematogaster (20)	*Crematogaster concava* Emery, 1899	42.86	0
		Crematogaster (*Decacrema*) sp.	0	14.29
		Crematogaster (*Oxygyne*) sp.1	0	14.29
		Crematogaster (*Oxygyne*) sp.2	0	14.29
		Crematogaster (*Sphaerocrema*) sp.1	28.57	28.57
		Crematogaster (*Sphaerocrema*) sp.2	0	57.14
		Crematogaster acis	28.57	28.57
		Crematogaster bequaerti Forel, 1913	28.57	0
		Crematogaster fauconneti	28.57	14.29
		Crematogaster melanogaster Emery, 1895	14.29	0
		Crematogaster mottazi Santschi, 1928	14.29	0
		Crematogaster rugosa André, 1895	28.57	0
		Crematogaster similis Stitz, 1911	14.29	0
		Crematogaster sp.1	42.86	28.57
		Crematogaster sp.2	28.57	14.29
		Crematogaster sp.3	57.14	0
		Crematogaster sp.4	28.57	0
		Crematogaster striatula Emery, 1892	14.29	28.57
		Crematogaster trautiveini	14.29	0
		Crematogaster zavattarii Menozzi, 1926	14.29	0
	Tetramorium (15)	*Tetramorium ataxium* Bolton, 1980	0	14.29
		Tetramorium aculeatum (Mayr, 1886)	71.43	57.14
		Tetramorium anguilinode Santschi, 1910	42.86	0
		Tetramorium bicarinatum (Nylander, 1846)	28.57	0
		Tetramorium brevispinosum (Stitz, 1910)	28.57	28.57
		Tetramorium coloreum Mayr, 1901	14.29	14.29
		Tetramorium gabonense (André, 1892)	0	42.86
		Tetramorium guineensis (Bernard, 1953)	57.14	0
		Tetramorium minisculum (Santschi, 1914)	14.29	0
		Tetramorium monardi (Santschi, 1937)	0	14.29
		Tetramorium pusillum (Emery, 1895)	14.29	0
		Tetramorium rugosum Taylor, 2007	42.86	14.29
		Tetramorium sp.1	28.57	28.57
		Tetramorium sp.2	14.29	14.29

		Tetramorium sp.3	14.29	0
Ponerinae (Lepeletier -Fargeau, 1835)	*Anochetus* (3)	*Anochetus nsp Cameroon FK*	0	14.29
		Anochetus bequarti Forel, 1913	28.57	0
		Anochetus sp.	14.29	0
	Odontomachus (1)	*Odontomachus troglodytes* Santsch, 1914	42.86	85.71
	Paltothyreus (3)	*Paltothyreus sjöstedti*	14.29	0
		Paltothyreus subiridescens (Wheeler, 1922)	14.29	0
		Paltothyreus tarsatus Fabricius, 1798	85.71	85.71
	Hypoponera (1)	*Hypoponera cognata* Santshi, 1912	0	28.57
	Leptogenis (1)	*Leptogenis vindicis* Bolton, 1975	14.29	28.57
	Loboponera (1)	*Loboponera* sp.	0	14.29
	Phrynoponera (2)	*Phrynoponera bequaerti* Wheeler, 1922	0	14.29
		Phrynoponera gabonensis André, 1892	14.29	14.29

Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park; Fo= Frequency of occurrence. The numbers into parenthesis in column 2 represent the numbers of species for each genus recorded.

III.1.3.1.4.2 Effect of habitat type on ants' occurrence

III.1.3.1.4.2.1 Occurrence of ant subfamilies

In Deng-Deng National Park (DDNP), Myrmicinae was the most common (Fo>50%) subfamily in most habitat types except in GF and GS, dominated by Formicinae. While, in Mpem et Djim National Park (MDNP), Formicinae was the most common subfamily except in SF where Myrmicinae was the most frequent. Cerapachyinae and Dorilynae were uncommon in all sampled habitat types with only one and two species collected respectively (Table XXXII).

Table XXXII : Frequency of occurrence of ant species subfamilies in each habitat type

Subfamilies	**DDNP**					**MDNP**				
	GF	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
NS →	80	80	80	80	80	40	40	80	80	40
Cerapachynae	0	0	0	5.56	0	0	0	0	0	0
Dolichoderinae	90	50	45	50	30	40	0	94.44	79.17	10
Dorylinae	0	0	10	16.67	20	0	0	11.11	12.5	0
Formicinae	100	100	45	38.89	10	80	80	94.44	75	100
Myrmicinae	60	80	50	50	30	80	70	88.89	87.5	80
Ponerinae	80	60	40	55.56	30	60	90	83.33	54.17	90

NS= Number of samples. Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; GS=Grassland Savanna;

III.1.3.1.4.2.2 Occurrence of ant species in each habitat type

In Deng-Deng National Park (DDNP), four species were common (Fo>50%) to the GF ant communities, including *Tapinoma melanocephalum*, *Paltothyreus tarsatus*, *Camponotus maculatus*, and *Camponotus brutus.* Three other common species different to previous occurred in GF in Mpem et Djim National Park (MDNP), including *Camponotus acvapimensis*, *Crematogaster* (*Sphaerocrema*) sp.2, and *Odontomachus troglodytes.* In MDNP and DDNP GS, six commonly encountered species, some different were recorded, including mainly *Tapinoma melanocephalum*, *Camponotus brutus*, *Pheidole* sp.1, *Paltothyreus tarsatus*, *Camponotus acvapimensis*, and *Polyrachis militaris*. Except for *Pheidole* sp.1, none of these species were common in DDNP NPF, while in MDNP, only *Tapinoma melanocephalum* and *Paltothyreus tarsatus* were commonly sampled in NPF, the same trend was observed in SF in this park. In DDNP SF only *Paltothyreus tarsatus* was common. *Odontomachus troglodytes*, *Polyrachis militaris*, *Camponotus acvapimensis*, and *Pheidole magri* were common in MDNP WS, while none of the species were common in DDNP WS. The same pattern was observed in both parks' Sl. and Sw. habitats.

In both protected areas' ant communities, the GF of Mpem et Djim National Park (MDNP) recorded two species less commonly sampled (25% ≤ Fo < 50%), including *Camponotus pompeius* and *Tetramorium aculeatum*. The GF in Deng-Deng National Park (DDNP) did not record less common ant species. A similar trend was observed in MDNP's GS, where *Camponotus maculatus* and *Crematogaster* (*Sphaerocrema*) sp.1 were less common. In both park's NPF, five species (in MDNP) and six (in DDNP) were recorded, including *Technomyrmex* sp.1, *Technomyrmex* sp.2, *Camponotus maculatus*, *Pheidole* sp.3, and *Paltothyreus tarsatus* in DDNP. *Technomyrmex* sp.1, *Anoplolepis tenella*, *Lepisiota monardi*, *Pheidole albidula*, *Pheidole megacephala*, and *Tetramorium aculeatum* were collected in MDNP. In SF, five species were less common in DDNP, specifically *Tapinoma melanocephalum*, *Camponotus brutus*, *Camponotus maculatus*, *Technomyrmex* sp.1, and *Pheidole* sp.1. The two previous species were also less common in MDNP's SF along with *Tetramorium aculeatum* and *Pheidole megacephala.* Only *Paltothyreus tarsatus* was the less common species recorded in DDNP's Sw.. In MDNP, Sl. habitat had no species less common. The WS of both parks recorded respectively three (DDNP) and two species (MDNP) considered to be less common. These are *Paltothyreus tarsatus Tapinoma melanocephalum*, *Tetramorium aculeatum* in DDNP, and *Paltothyreus tarsatus* and *Crematogaster* (*Sphaerocrema*) sp.2 in MDNP.

In Deng-Deng National Park (DDNP) ant communities, nine species recorded in GF, 25 species in GS, 39 species in NPF, 26 species in SF, three species in SW, and nine species in WS that were considered to be uncommon (that is, poorly represented in samples) (Fo <25%; see Table XXXIII). In MDNP, we recorded 10 species in GF, five species in GS, 25 species in NPF, 35 species in SF, nine species in Sl., and four species in WS were considered to be uncommon in samples (see Table XXXIII).

Table XXXIII : Frequency of occurrence of ant species in each habitat type except swamp and saltwork

		DDNP					**MDNP**				
Subfamilies	**Species**	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
	Number of samples →	80	80	80	80	80	40	40	80	80	40
Cerapachynae	*Cerapachys foreli*	0	0	0	5.56	0	0	0	0	0	0
Dolichoderinae	*Axinidris murialae*	0	0	5	0	0	0	0	0	0	0
	Tapinoma melanocephalum	80	50	15	44.44	30	0	0	94.44	83.34	0
	Technomyrmex sp.1	0	0	30	27.78	0	20	0	44.44	41.67	10
	Technomyrmex sp.2	0	0	25	11.11	0	20	0	0	0	0
Dorylinae	*Dorylus braunsi*	0	0	0	5.56	10	0	0	0	0	0
	Dorylus nigricans	0	0	10	11.11	10	0	0	11.11	12.5	0
Formicinae	*Anoplolepis carinata*	0	10	0	0	0	0	0	50	50	0
	Anoplolepis sp.	0	0	0	5.56	0	0	0	0	0	0
	Anoplolepis tenella	0	0	0	0	0	0	0	27.78	20.83	0
	Camponotus vividus	0	0	0	0	0	0	0	0	8.33	0
	Camponotus acvapimensis	10	50	0	0	0	50	80	5.56	4.17	80
	Camponotus brutus	90	20	20	27.78	10	0	0	16.67	12.5	0
	Camponotus chrysurus	0	0	0	0	0	0	0	0	4.17	0
	Camponotus congolensis	0	10	0	0	0	0	0	0	0	0
	Camponotus conradti	0	0	0	0	0	0	0	5.56	4.17	0
	Camponotus flavomaginatus	0	10	5	0	0	0	0	16.67	12.5	0
	Camponotus foraminosus	0	0	5	0	0	0	0	11.11	12.5	0
	Camponotus maculatus	60	60	35	27.78	0	20	40	16.67	16.67	40
	Camponotus pompeius	0	0	0	0	0	40	20	5.56	0	40
	Camponotus sp.1	0	10	0	0	0	0	0	0	0	0
	Camponotus sp.2	0	10	0	0	0	0	0	0	0	0
	Camponotus sp.3	0	20	0	0	0	0	0	0	0	0
	Camponotus sp.4	0	0	0	0	0	0	0	0	0	0
	Lepisiota capensis	0	0	10	0	0	0	0	0	4.17	0
	Lepisiota foreli	0	0	0	0	0	0	0	0	0	0
	Lepisiota guineensis	0	0	0	0	0	0	0	0	8.33	0
	Lepisiota monardi	0	20	0	0	0	0	0	27.78	4.17	0
	Lepisiota n sp Cameroun FK	0	0	0	0	0	0	0	0	4.17	0
	Lepisiota negrisetosa	0	0	0	0	0	0	0	0	0	0
	Lepisiota nganguela	0	10	0	0	0	0	0	0	0	0
	Lepisiota sp.	0	20	10	0	0	0	0	0	0	0
	Lepisiota spinosior	0	10	0	0	0	0	0	0	0	0
	Oecophylla longinoda	0	0	5	0	0	0	0	0	0	20

	Parapartrechina brunnella	0	0	5	0	0	0	0	0	0	0
	Paratrechina concinnata	0	0	0	0	0	0	0	5.56	0	0
	Plagiolepis sp.	0	0	0	5.56	0	0	0	0	0	0
	Polyrachis decemdentata	10	0	5	5.56	0	0	0	0	4.17	0
	Polyrachis militaris	0	50	10	0	0	30	50	5.56	12.5	70
Myrmicinae	*Cardiochondyla wasmani*	0	0	14.29	0	0	0	0	0	0	0
	Carebera sp.	0	10	5	0	0	0	0	0	0	0
	Cataulacus guineensis	0	0	0	0	0	0	0	0	0	10
	Cataulacus weissi	0	0	5	0	0	0	0	0	0	0
	Crematogaster concava	0	0	20	11.11	0	0	0	0	0	0
	Crematogaster (Decacrema) sp.	0	0	0	0	0	10	0	0	0	0
	Crematogaster (Oxygyne) sp.1	0	0	0	0	0	0	0	0	0	0
	Crematogaster (Oxygyne) sp.2	0	0	0	0	0	0	10	0	0	0
	Crematogaster (sphaerocrema) sp.1	10	20	0	0	0	10	0	0	0	30
	Crematogaster (sphaerocrema) sp.2	0	0	0	0	0	50	40	0	0	10
	Crematogaster acis	0	0	5	0	0	0	0	5.56	4.17	0
	Crematogaster bequaerti	0	20	0	16.67	0	0	0	0	0	0
	Crematogaster fauconneti	10	0	0	0	0	0	0	0	4.17	0
	Crematogaster melanogaster	0	0	5	0	0	0	0	0	0	0
	Crematogaster mottazi	0	0	0	5.56	0	0	0	0	0	0
	Crematogaster rugosa	0	10	0	0	0	0	0	0	0	0
	Crematogaster similis	0	10	0	0	0	0	0	0	0	0
	Crematogaster sp.1	0	20	15	11.11	0	0	0	11.11	4.17	0
	Crematogaster sp.2	0	10	5	0	0	0	0	5.56	0	0
	Crematogaster sp.3	0	10	5	5.56	0	0	0	0	0	0
	Crematogaster sp.4	0	0	0	5.56	0	0	0	0	0	0
	Crematogaster striatula	0	0	0	0	0	0	0	5.56	12.5	0
	Crematogaster trautiveini	0	0	0	0	0	0	0	0	0	0
	Crematogaster zavattarii	0	0	0	0	0	0	0	0	0	0
	Decamorium uelense	0	0	0	0	0	0	0	0	0	0
	Monomorium borlei	0	0	0	0	10	0	0	0	0	0
	Monomorium mayri	0	0	0	0	10	0	0	0	0	0
	Monomorium sp.	0	0	0	0	20	0	0	0	0	0
	Myrmicaria opaciventris	0	0	0	5.56	0	0	0	0	0	0
	Pheidole albidula	0	0	0	5.56	0	0	0	27.78	16.67	0
	Pheidole concinna	0	0	0	0	0	0	0	0	0	0
	Pheidole magri	0	0	0	0	0	40	50	0	0	60
	Pheidole megacephala	30	0	10	5.56	0	0	0	38.89	33.33	0
	Pheidole mentita	10	0	0	0	0	0	20	0	4.17	0

	Pheidole minima	0	10	0	0	0	0	0	0	0	0
	Pheidole pulchella	0	0	0	0	0	0	0	0	12.5	0
	Pheidole rohani	0	0	0	0	0	0	0	16.67	0	0
	Pheidole sp.1	10	50	50	38.89	0	0	0	16.67	25	0
	Pheidole sp.2	10	10	20	11.11	0	10	0	0	0	0
	Pheidole sp.3	0	0	15	5.56	0	0	0	0	0	0
	Pheidole speculifera	0	0	0	0	0	0	0	0	12.5	0
	Tetramorium ataxium	0	0	0	0	0	0	0	0	4.17	0
	Tetramorium aculeatum	20	10	15	11.11	30	40	20	44.44	41.67	0
	Tetramorium anguilinode	0	10	20	11.11	0	0	0	0	0	0
	Tetramorium bicarinatum	0	0	5	0	0	0	0	0	0	0
	Tetramorium brevispinosum	0	0	5	0	0	0	0	16.67	16.67	0
	Tetramorium coloreum	0	0	5	0	0	10	0	0	0	0
	Tetramorium gabonense	0	0	0	0	0	0	10	16.67	12.5	0
	Tetramorium guineensis	10	20	0	0	0	0	0	0	0	0
	Tetramorium minisculum	0	0	0	5.56	0	0	0	0	0	0
	Tetramorium monardi	0	0	0	0	0	0	0	0	4.17	0
	Tetramorium pusillum	0	0	5	0	0	0	0	0	0	0
	Tetramorium rugosum	0	0	10	5.56	10	0	0	0	4.17	0
	Tetramorium sp.1	0	0	10	5.56	0	0	0	5.56	8.33	0
	Tetramorium sp.2	0	0	5	0	0	10	0	0	0	0
	Tetramorium sp.3	0	0	0	5.56	0	0	0	0	0	0
Ponerinae	*Anochetus nsp Cameroon FK*	0	0	0	0	0	0	0	5.56	0	0
	Anochetus bequarti	0	0	10	11.11	0	0	0	0	0	0
	Anochetus sp.	0	0	0	0	10	0	0	0	0	0
	Hypoponera cognata	0	0	0	0	0	10	0	0	4.17	0
	Leptogenis vindicis	10	0	0	0	0	0	0	5.56	0	0
	Loboponera sp.	0	0	0	0	0	0	0	5.56	0	0
	Odontomachus troglodytes	0	20	5	5.56	0	50	70	5.56	12.5	70
	Paltothyreus sjöstedti	0	0	5	0	0	0	0	0	0	0
	Paltothyreus subiridescens	0	0	5	0	0	0	0	0	0	0
	Paltothyreus tarsatus	80	60	40	55.56	30	20	50	83.33	54.17	40
	Phrynoponera bequaerti	0	0	0	0	0	0	0	0	4.17	0
	Phrynoponera gabonensis	0	0	0	0	0	0	0	5.56	0	0

Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; GS=Grassland Savanna.

III.1.3.1.4.3 Seasonal variation of ants' occurrence

In the dry season, five species were common (with Fo≥50%) in samples from DDNP's ant community, namely *Camponotus brutus*, *Crematogaster concava*, *Pheidole megacephala*, *Pheidole* sp.1 and *Paltothyreus tarsatus*. A different pattern was observed in samples from MDNP's dry season ant community where four species, different from those from DDNP except *Paltothyreus tarsatus* were common, including *Tapinoma melanocephalum*, *Technomyrmex* sp.1, and *Anoplolepis carinata*. Fifteen ant species were common in DDNP's rainy season, including *Tapinoma melanocephalum*, *Technomyrmex* sp.1, *Technomyrmex* sp.2, *Camponotus acvapimensis*, *Camponotus brutus*, *Camponotus maculatus*, *Polyrachis militaris*, *Crematogaster* sp.1, *Pheidole* sp.2, *Pheidole* sp.3, *Pheidole* sp.1, *Tetramorium aculeatum* , *Tetramorium anguilinode*, *Tetramorium guineensis* and *Paltothyreus tarsatus,* while 11 species were common in MDNP's rainy season, mainly species in the genus *Camponotus* namely *Ca. acvapimensis*, *Ca. maculatus*, *Ca. pompeius* and also *Paltothyreus tarsatus* *Anoplolepis tenella*, *Polyrachis militaris*, *Crematogaster* (*Sphaerocrema*) sp.1, *Pheidole magri*, *Tetramorium aculeatum*, *Odontomachus troglodytes* and *Tapinoma melanocephalum*.

Four ant species were less common (accessory) in samples from DDNP's ant community during the dry season with 25% ≤ Fo< 50%, including *Camponotus maculatus*, *Crematogaster bequaerti*, *Monomorium borlei* and *Pheidole albidula*. Six species were less commonly sampled in MDNP, including *Lepisiota monardi*, *Pheidole megacephala*, *Pheidole mentita*, *Pheidole* sp.1, *Tetramorium gabonense* and *Tetramorium brevispinosum.* Five species were less commonly sampled in DDNP ant's community during the rainy season, including *Dorylus nigricans*, *Polyrachis decemdetata*, *Crematogaster* sp.4, *Tetramorium* sp.1 and *Arnochetus bequarti.* Six species were less commonly sampled in MDNP during the rainy season, including *Technomyrmex* sp.1, *Dorylus nigricans*, *Camponotus flavomaginatus*, *Crematogaster* (*Sphaerocrema*) sp.1, *Crematogaster* sp.1 and *Pheidole* sp.1.

In the dry season, 48 species recorded in the DDNP and 34 species in MDNP were rarely or uncommonly collected in the ant communities investigated (with Fo<25%; see Table XXXIV). In the rainy season, 21 species in the DDNP and 16 species in MDNP with Fo <25% were rare (uncommon; Table XXXIV).

Table XXXIV: Frequency of occurrence of ant species in each park per season

		DDNP		MDNP	
Sub-families	**Species**	**Dry**	**Rainy**	**Dry**	**Rainy**
	Number of samples →	240	240	200	280
Cerapachynae	*Cerapachys foreli*	0	20	0	0
Dolichoderinae	*Axinidris murialae*	5	0	0	0
	Tapinoma melanocephalum	100	100	91.67	100
	Technomyrmex sp.1	0	80	62.5	30
	Technomyrmex sp.2	0	70	0	20
Dorylinae	*Dorylus braunsi*	0	20	0	0
	Dorylus nigricans	5	30	4.17	30
	Anoplolepis carinata	5	0	54.17	0
	Anoplolepis sp.	0	10	0	0
	Anoplolepis tenella	0	10	8.33	70
	Camponotus vividus	0	0	8.33	0
	Camponotus acvapimensis	5	50	8.33	100
	Camponotus brutus	65	70	16.67	20
	Camponotus chrysurus	0	0	4.17	0
	Camponotus congolensis	5	0	0	0
	Camponotus conradti	0	0	8.33	0
	Camponotus flavomaginatus	5	10	8.33	40
	Camponotus foraminosus	5	0	20.83	0
	Camponotus maculatus	45	90	8.33	100
	Camponotus pompeius	0	0	4.17	70
	Camponotus sp.1	5	0	0	0
	Camponotus sp.2	15	0	0	0
	Camponotus sp.3	10	0	0	0
	Camponotus sp.4	0	10	0	0
	Lepisiota capensis	15	0	4.17	0
	Lepisiota foreli	5	0	0	0
	Lepisiota guineensis	0	0	8.33	0
	Lepisiota monardi	15	0	25	0
	Lepisiota n sp Cameroun FK	0	0	4.17	0
	Lepisiota negrisetosa	5	0	0	0
	Lepisiota nganguela	5	0	0	0
	Lepisiota sp.	10	20	0	0
	Lepisiota spinosior	5	0	0	0
	Oecophylla longinoda	5	0	0	20
	Parapartrechina brunnella	5	0	0	0
	Paratrechina concinnata	0	0	4.17	0
	Plagiolepis sp.	0	10	0	0
	Polyrachis decemdentata	5	30	4.17	0
	Polyrachis militaris	20	50	12.5	100
Myrmicinae	*Cardiochondyla wasmani*	0	10	0	0
	Carebera sp.	5	10	0	0
	Cataulacus guineensis	0	0	0	10
	Cataulacus weissi	0	20	0	0
	Crematogaster concava	50	0	0	0
	Crematogaster (Decacrema) sp.	0	0	0	10
	Crematogaster (Oxygyne) sp.1	0	0	0	10
	Crematogaster (Oxygyne) sp.1	0	0	0	10
	Crematogaster (sphaerocrema) sp.1	15	0	0	30
	Crematogaster (sphaerocrema) sp.1	0	0	0	60
	Crematogaster acis	10	0	8.33	0
	Crematogaster bequaerti	35	0	0	0
	Crematogaster fauconneti	10	0	4.17	0
	Crematogaster melanogaster	5	0	0	0
	Crematogaster mottazi	5	0	0	0
	Crematogaster rugosa	10	0	0	0
	Crematogaster similis	5	0	0	0
	Crematogaster sp.1	0	60	0	30

	Crematogaster sp.2	0	10	0	0
	Crematogaster sp.3	0	10	0	10
	Crematogaster sp.4	0	40	0	0
	Crematogaster striatula	5	0	16.67	0
	Crematogaster trautiveini	5	0	0	0
	Crematogaster zavattarii	5	0	0	0
	Decamorium uelense	5	0	0	0
	Monomorium borlei	25	0	0	0
	Monomorium mayri	10	0	0	0
	Monomorium sp.	15	0	0	0
	Myrmicaria opaciventris	0	10	0	0
	Pheidole albidula	25	0	75	0
	Pheidole concinna	5	0	0	0
	Pheidole magri	0	0	0	90
	Pheidole megacephala	100	0	45.83	0
	Pheidole mentita	0	10	41.67	20
	Pheidole minima	0	20	0	0
	Pheidole pulchella	5	0	12.5	0
	Pheidole rohani	5	0	12.5	0
	Pheidole sp.1	100	90	29.17	30
	Pheidole sp.2	0	70	0	10
	Pheidole sp.3	0	50	0	0
	Pheidole speculifera	5	0	12.5	0
	Tetramorium ataxium	0	0	4.17	0
	Tetramorium aculeatum	0	90	4.17	100
	Tetramorium anguilinode	10	60	0	0
	Tetramorium bicarinatum	10	0	0	0
	Tetramorium brevispinosum	10	0	25	0
	Tetramorium coloreum	5	0	0	10
	Tetramorium gabonense	0	0	25	10
	Tetramorium guineensis	0	50	0	0
	Tetramorium minisculum	5	0	0	0
	Tetramorium monardi	0	0	4.17	0
	Tetramorium pusillum	5	0	0	0
	Tetramorium rugosum	40	0	4.17	0
	Tetramorium sp.1	0	30	12.5	0
	Tetramorium sp.2	0	10	0	10
	Tetramorium sp.3	0	10	0	0
Ponerinae	*Anochetus nsp Cameroon FK*	0	0	4.17	0
	Anochetus bequarti	0	30	0	0
	Anochetus sp.	0	10	0	0
	Hypoponera cognata	0	0	4.17	10
	Leptogenis vindicis	0	10	4.17	10
	Loboponera sp.	0	0	4.17	0
	Odontomachus troglodytes	10	20	0	100
	Paltothyreus sjöstedti	5	0	0	0
	Paltothyreus subiridescens	5	0	0	0
	Paltothyreus tarsatus	90	100	70.83	100
	Phrynoponera bequaerti	0	0	4.17	0
	Phrynoponera gabonensis	0	10	0	10

Park codes are MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park; Fo= Frequency of occurrence.

III.1.3.1.5 Similarity of ants' communities

III.1.3.1.5.1 Similarity between pairs of habitats

Based on the Bray-Curtis index, the highest similarity of ant communities was observed between GS and GF (Cn=0.532), followed by NPF and SF (Cn=0.526), then GF, and WS (Cn=0.575 and Cn=0.434), respectively (see Table XXXV).

Table XXXV : Bray-Curtis' dissimilarity indices comparing pairs of habitat types in

GS	NPF	SF	Sl.	Sw.	WS	
0.532	0.081	0.114	0.147	0.072	0.434	GF
	0.057	0.125	0.182	0.018	0.471	GS
		0.526	0.009	0.012	0.076	NPF
			0.013	0.016	0.096	SF
				0.008	0.182	Sl.
					0.027	Sw.
						WS

Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The numbers in bold denote a higher value of Bray-Cutis index. The greater are the index values (near to 1) more similar are the pairs of habitats.

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III.1.3.1.5.2 Similarity of communities' species composition

For both parks, ant assemblages in MDNP savanna habitats (MDSL, MDWS, MDGS, and MDGF) and DDGF, MDSF, MDNPF and DDSW have distinct species compositions (Fig. 44). Likewise, in DDNP forest habitats (DDNPF, DDSF) and savanna habitats (DDGS and DDWS) species assemblages form a distinct group. *Tetramorium aculeatum*, *Tetramorium gabonense*, *Hypoponera cognata*, *Crematogaster* (*Sphaerocrema*) sp.1, and *Polyrachis militaris* were not specific to any habitat types (see Fig. 44).

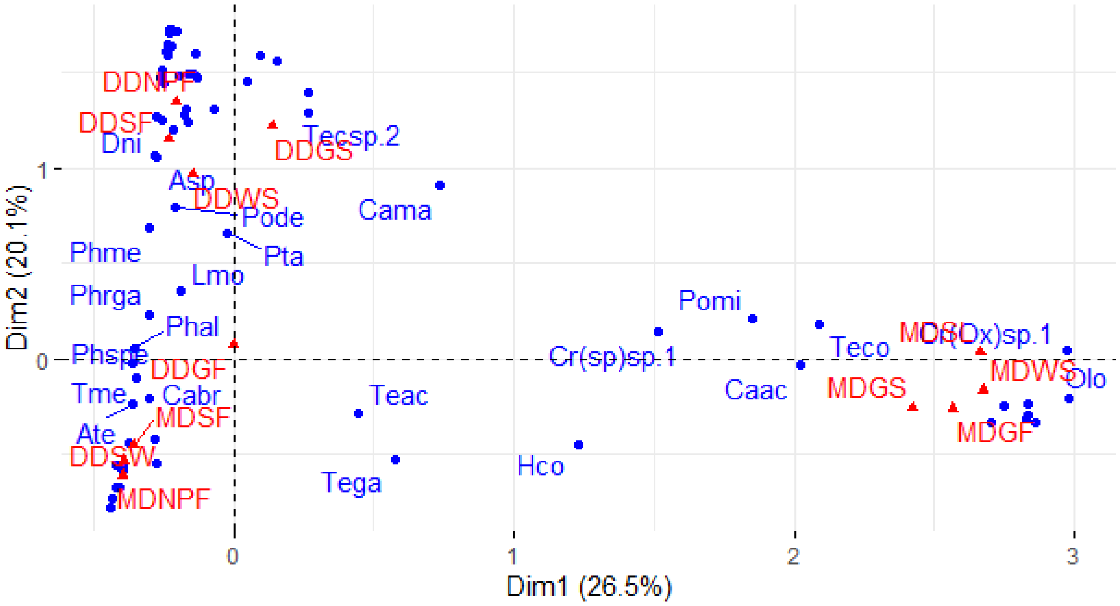

Figure 44: Correspondence Analysis showing the association between each ant species and each habitat type in each national park. Dimension 1 (Dim1) contribute to explaining 26.5% of the variance and Dimension 2 (Dim2) explained 20.1%. The blue circles represent ants and the red triangles represent each habitat type. Some species points (circles) are unlabeled due to overlapping with other points. Habitat and park codes are DDNPF= Deng Deng Near primary forest, DDSF= Deng Deng Secondary Forest, DDGS= Deng Deng grassland savanna, DDWS= Deng Deng Woodland savanna, DDGF= Deng Deng Gallery Forest, MDNPF= Mpem et Djim Near primary forest, MDSF= Mpem et Djim Secondary Forest, MDGS= Mpem et Djim grassland savanna, MDWS= Mpem et Djim Woodland savanna, MDGF= Mpem et Djim Gallery forest. Species codes are: Asp.=*Anoplolepis* sp.; Ate=*Anoplolepis tenella*; Cabr= *Camponotus brutus*; Caac= *Camponotus acvapimensis*; Crsp. 1= *Crematogaster* sp.1; Cama=*Camponotus maculatus*; Cr(Ox)sp. 1= *Crematogaster* (*Oxygyne*) sp.1; Dni= Dorylis nigricans; Hco= *Hypoponera cognata;* Lmo=*Lepisiota monardi*; Olo= *Oecophila longinoda*; Pode= *Polyrachis decemdetata;* Pomi= *Polyrachis militaris*; *Pta= Paltothyreus tarsatus;* Phal=

*Pheidole albidula*Phme= *Pheidole megacephala;* Phrga=*Phrynoponera gabonensis;* Phspe= *Pheidole speculifera;* Tecsp2= *Technomyrmex sp.*2; Teac= *Tetramorium acculeatum*; Tme= *Tapinoma melanocephalum*; Tega=*Tetramorium gabonense*; Teco= *Tetramorium coloreum.*

II.1.3.1.5.3 Similarity of ant's communities between habitat types

Ant communities of MDSL, MDWS, and MDSW are the most similar. They are also similar to DDWS and DDGS's communities. DDNPF and DDSF are very similar with close nodes that are highly significant (95% AU p-value). MDNPF and MDSF are more similar together but not significantly different (90% AU p-value) to other habitat types (see Fig. 45).

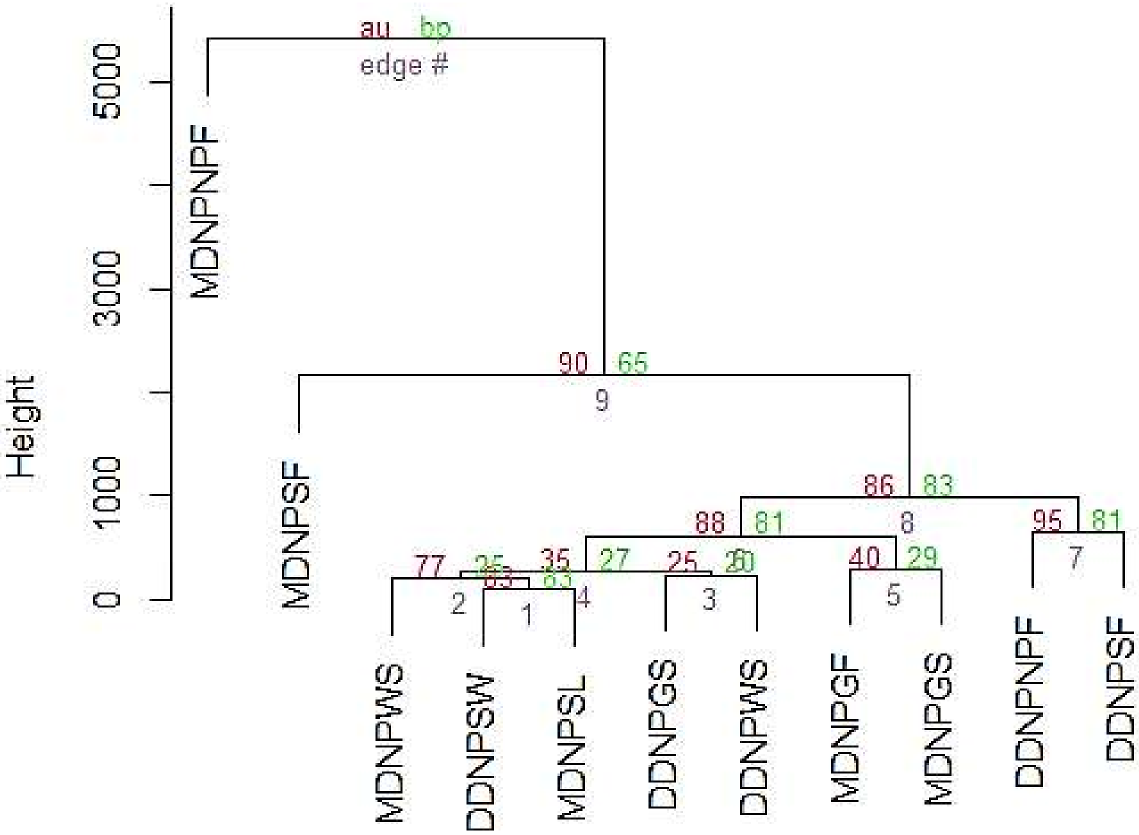

Figure 45: Dendrogram showing nodes formed by ant communities of different habitat types. Distances are "ecludian" and the cluster method is "complete". Representation of significative clusters following Bootstrap provides red and green numbers on the graph (the gray numbers are the node number). The green number is the Bootstrap Probability * 100 (BP) and has the most straightforward interpretation. The red number is the Approximately Unbiased p-value * 100 (AU) and is a corrected version of BP to limit bias. Parks codes are: MDNP=Mpem et Djim National Park, DDNP=Deng-Deng National Park; Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw= Swamp.

III.1.3.2 Potential termite preys

A total of 89 species of termite representing 33 genera and 10 subfamilies were recorded in both parks from a sample of 56,798 individuals.

III.1.3.2.1 Species

Families

Termitidae Latreille 1802 was the most speciose family with 86 species (96.62% of all termite species), while Rhinotermitidae had 3 species (3.37%).

Subfamilies

Macrotermitinae Kemner 1934 was the most common subfamily in both protected areas represented by 29 species (32.58%) in DDNP and 28 species (31.46%) in MDNP followed by Cubitermitinae Weidner, 1956 [26 species (29.21%) in DDNP and 19 species (21.34%) in MDNP], respectively and Nasutermitinae Hare 1937 [with 12 species (13.48%) in MDNP and 10 species (11.23%) in DDNP (Fig.46)]. Rhinotermitinae, Apicotermitinae, Coptotermitinae were least rich. The percentage of species was significantly higher (χ^2=59.2, df=7, p=0.001) in Macrotermitinae and Cubitermitinae other subfamilies.

Genera

The most species-rich genus in both parks was *Isognathotermes* Sjöstedt 1926 [13 species (14.60%) in DDNP and 10 species (11.23%) in MDNP], followed by *Microtermes* Wasmann 1902 with seven species (7.86%) in MDNP and eight species (8.98%) in DDNP and *Macrotermes* Holmgren 1909 with seven species (7.86%) in MDNP and three species (3.37%) in DDNP.

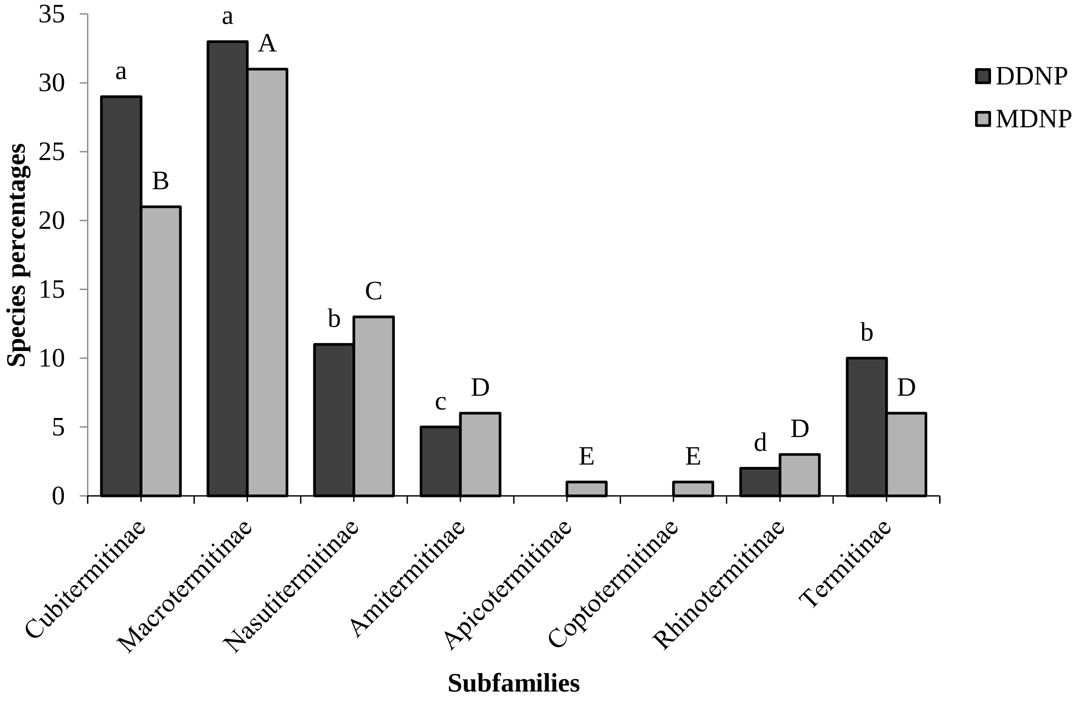

Figure 46: Percentages of termite species per subfamily in each protected area (a) Deng Deng National Park (DDNP) and (b) Mpem et Djim National Park (MDNP). Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species percentage between different subfamilies in different parks.

III.1.3.2.1.1 Variation of species percentages between protected areas

A total of 31,625 individual termites were sampled in MDNP, comprising 66 species (74.15% of all sampled species), 24 genera (72.72% of all sampled genera), two families (Rhinotermitidae and Termitidae), and eight subfamilies. In DDNP, we sampled 25,173 individuals representing 69 species (77.52%), 28 genera (84.85%), two families the same at MDNP, and seven subfamilies. Termite species percentage was not significantly different ($\chi^2=0.29$, df=1, p=0.51) in DDNP than in MDNP.

III.1.3.2.1.2 Variation of species percentages between habitat types

In DDNP, near primary forest, with 46 species (49.44% of all sampled species), yielded the highest termite species percentages followed by grassland savanna (33 species, 33.37%) and secondary forest (30 species, 30.71%). In MDNP, NPF had the highest species percentages (35 species, 39.33%), followed by the SF (34 species, 38.20%), GF (24 species, 26.97%), then WS and GS (22 species, 24.72%). Termite species percentages were significantly higher in NPF, SF and GS ($p<0.0001$; Fig.47) in DDNP than in other habitats. While, in MDNP, forest habitats (NPF, SF) and savanna habitats (GS, GF and WS) significantly dominated ($p<0.0001$) the other habitats.

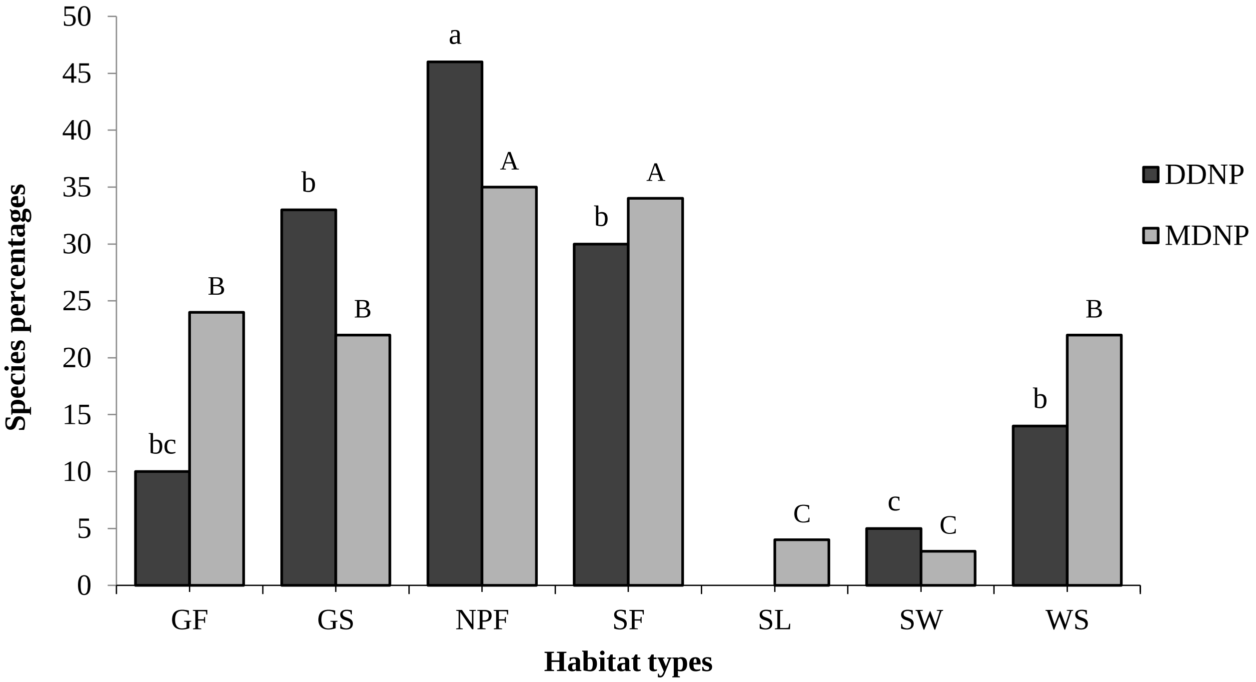

Figure 47: Percentages of termite species per habitat type in Deng Deng National Park (DDNP) and Mpem et Djim National Park (MDNP). Habitat codes are: GF=gallery forest; NPF=near primary forest; WS=woodland savanna; Sl.=saltworks; GS=grassland savanna; Sw.= swamp; SF=secondary forest. Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species percentage between different habitat types in different parks.

III.1.3.2.1.3 Seasonal variation of termite species percentages

Termite species percentage in MDNP secondary forest was significantly higher ($\chi^2=4.66$, df=1, p=0.03) during the dry season than the rainy season. In DDNP woodland savanna termite species percentage was significantly higher ($\chi^2=11.26$, df=1, p=0.0007) during the rainy season. Except for GF, GS, Sl., and WS not sampled in MDNP during the dry season (Fig. 48a,b). All other habitat types and parks termite species percentages had no significant differences (p>0.05) between both dry and rainy seasons.

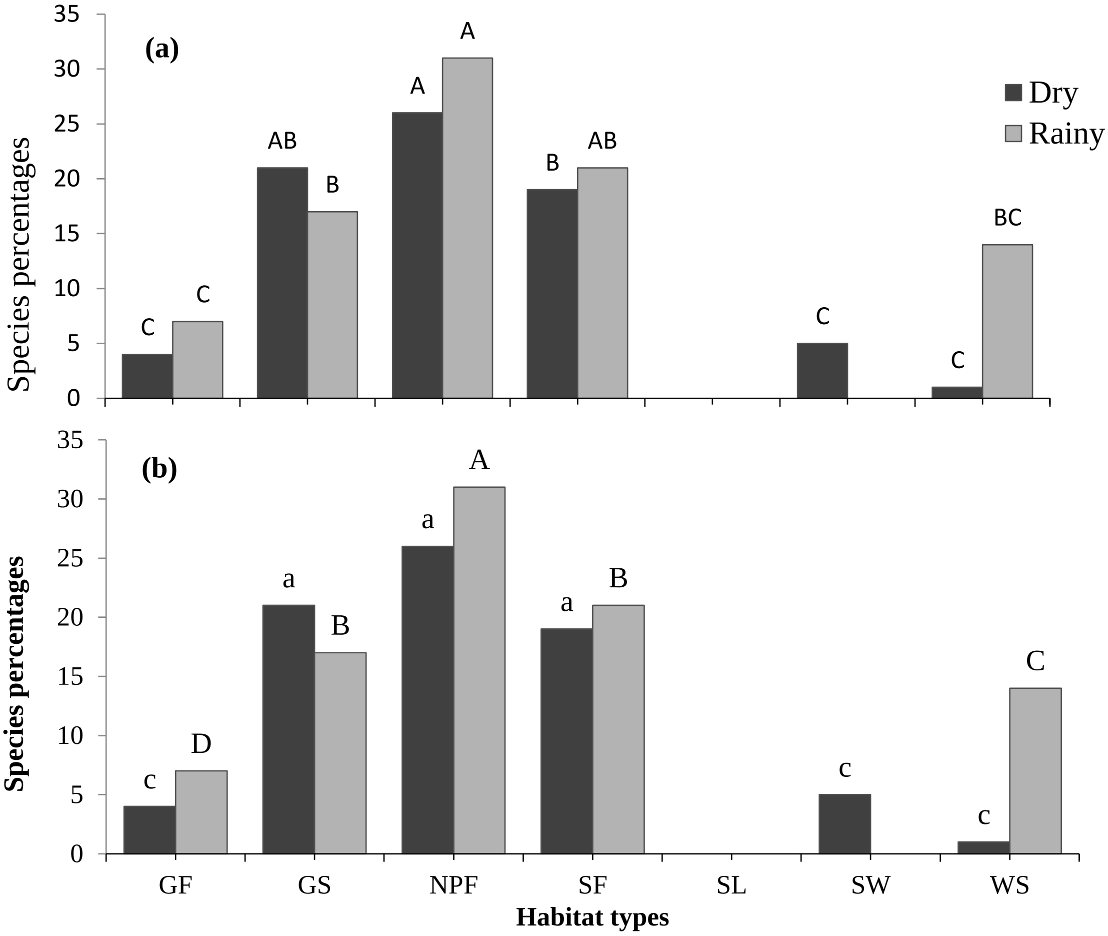

Figure 48: Percentages of termite species sampled in dry and rainy seasons per habitat type in (a) Deng Deng National Park (DDNP) and (b) Mpem et Djim National Park (MDNP). Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species richness between seasons in different habitat types in different parks.

III.1.3.2.2 Estimators of species richness and termites' sampling success

Overall, the termite species sampling success means were 76.51% in DDNP and 70.45% in MDNP indicating that for these parks, an estimated 29.55% and 23.49% of termite species respectively, remained uncollected.

III.1.3.2.2.1 Estimators of species richness per parks

In DDNP, the Jack 2 metric indicates the lowest sampling success (67.90%) meaning that a maximum of 32.10% of termite species are estimated to have been missed. A similar trend is observed in MDNP where the Jack 2 and Chao metrics indicated that respectively 64.07% and 74.15 % of the termite faunas were sampled (see Table XXXVI).

Table XXXVI: Termite species richness and sampling success from species richness estimators by protected areas.

	Parks	
Estimators	**MDNP**	**DDNP**
S_{obs}	66	74
ICE	94 (70.21)	104 (71.15)
Chao 2	89 (74.15)	94 (78.27)
Jack 1	91 (72.52)	97 (76.23)
Jack 2	103 (64.07)	109 (67.90)
Means	**95 (70.45)**	**98 (76.51)**

MDNP: Mpem et Dim National Park; DDNP: Deng Deng National Park; S_{obs}: Observed Species richness. The numbers in brackets indicate the sampling success in percent and those out of brackets are theoretical species richness.

III.1.3.2.2.2 Termite sampling success per habitats

Chao 2 with 95.84% of sampling success indicates that less than 4.06% of termite species remain unidentified in SF. The Jack 1 metric gave the highest sampling success values indicating that a minimum of 51.14% and a maximum of 86.46.17% were sampled in GF, GS, NPF, Sl., and Sw.. No asymptote was approached on rarefaction curves (Fig. 49).

Termite sampling success means varied from 49.75% in GS and GF to 91.1% in SF (see Table XXXVII) denoting that a maximum of 50.25% and a minimum of 18.9% of termite species respectively were missed in these habitat types. More samples are needed to record all the termite species of these habitat types, especially within different biotopes that were not sampled, such as the canopy and subterranean biotopes.

Table XXXVII: Estimators of termite species richness across habitat type.

	Habitat types						
Estimators	GS	GF	SF	NPF	Sl.	Sw.	WS
S_{obs}	42	37	44	55	4	8	37
ICE	87 (48.35)	77 (48.35)	48 (91.81)	75 (73.4)	8.5 (47)	17 (47.05)	63 (59.13)
Chao 2	126 (33.33)	111 (33.33)	**46 (95.84)**	72 (76.24)	8.5 (47)	17 (47.05)	55 (67.07)
Jack 1	69 (61.29)	60 (61.29)	51 (86.46)	77 (71.4)	7 (57)	14(57.14)	55 (67.07)
Jack 2	92 (45.68)	81 (45.68)	49 (90.37)	87 (62.98)	9 (44)	18 (44.44)	66 (56.24)
Means	**91 (49.75)**	**80(49.75)**	**49 (91.1)**	**75 (73.35)**	**7 (52.01)**	**14 (57.14)**	**58 (68.53)**

S_{obs} = Observed Species richness; The values in brackets are Theoretical Species richness (TSS) Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The numbers in brackets indicate the sampling success in percent and those out of brackets are theoretical species richness.

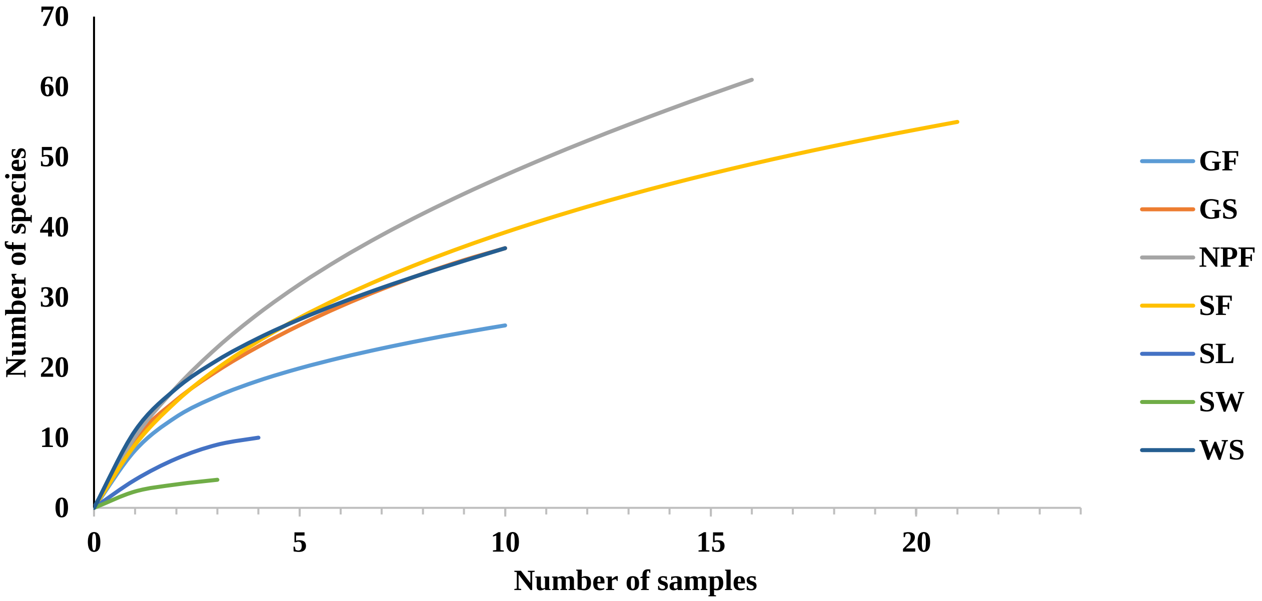

Figure 49: Sample rarefaction (Mao's tau) curves of termites in the different habitat types of the surveyed area. GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp

III.1.3.2.3 Variation of termites' occurrence

Overall, Cubitermitinae, Macrotermitinae, Nasutitermitinae and Sphaerotermitinae were the most commonly (Fo>50%) sampled subfamilies while, Coptotermitinae, Apicotermitinae, and Rhinotermitinae were uncommon (Fo≤25%). At the genera level, *Isognathotermes* and *Ancistrotermes* were the most commonly sampled genera with *Isognathotermes fungifaber* (Sjöstedt, 1896), *Ancistrotermes crucifer* (Sjöstedt, 1897) and *Pseudacanthotermes militaris* (Hagen, 1858) being the most common species (see Table XXXVII).

III.1.5.2.3.1 Variation between protected areas

Six termite species were commonly sampled in DDNP's termite community with Fo≥50%, namely *Isognathotermes zenkeri* (Desneux, 1904), *Isognathotermes fungifaber* (Sjöstedt, 1896), *Ancistrotermes crucifer* (Sjöstedt, 1897), *Macrotermes amplus* (Sjöstedt, 1899), *Microtermes osborni* Emerson, 1928, and *Pseudacanthotermes militaris* (Hagen, 1858). Five species were frequently sampled in MDNP's termite community, including *Iso. Ugandensis* (Fuller, 1923), *Iso. Gaigei* (Emerson, 1928), *Nitiditermes sankurensis* (Wasmann, 1911), *Polyspathotermes sulcifrons* (Wasmann, 1911), as well as *Ancistrotermes crucifer* (the same at DDNP).

A total of 28 species were less commonly sampled (with 25%≤Fo<50%), in DDNP's termite community including 10 species from the genus *Isognathotermes*, four *Microcerotermes*, three *Nasutitermes*, three *Microtermes*, and also *Fastigitermes jucundus* (Sjöstedt, 1907), *Furculitermes winifredae* Emerson, 1960, *Acanthotermes acanthothorax* (Sjöstedt, 1898), *Macrotermes lilljeborgi* (Sjöstedt, 1896), *Macrotermes natalensis* (Haviland, 1898), *Pseudacanthotermes spiniger* (Sjöstedt, 1900), *Fulleritermes tenebricus* (Silvestri, 1914), *Trinervitermes rhodesiensis* (Sjöstedt, 1911), and *Sphaerotermes sphaerothorax*. In MDNP termite communities, 27 species were less commonly sampled, including six species from *Isognathotermes* genus, two *Microcerotermes*, two *Nasutitermes,* three *Macrotermes*, two *Odontotermes*, three *Microtermes* species, and also *Mucrotermes osborni*, *Furculitermes winifredae*, *Pseudacanthotermes militaris*, *Trinervitermes occidentalis*, and *Sphaerotermes sphaerothorax*.

Thirty-five species recorded in the DDNP and 25 in MDNP were uncommon in the termite communities investigated (with Fo≤25%; see Table XXXVIII).

Table XXXVIII: Frequency of occurrence of termite species sampled in each national park.

Subfamilies	**Genera**	**Species**	**DDNP**	**MDNP**
		Number of samples →	**900**	**1050**
Apicotermitinae (1)	*Coxotermes* (1)	*Coxotermes* sp.	**0**	**17**
Coptotermitinae (1)	*Coptotermes* (1)	*Coptotermes sjostedti* Holmgren, 1911	0	17
Cubitermitinae (23)	*Crenetermes* (1)	*Crenetermes mixtus* Williams, 1962	17	0
	Isognathotermes (9)	*Isognathotermes ugandensis* (Fuller, 1923)	50	67
		Isognathotermes congoensis (Emerson, 1928)	33	50
		Isognathotermes fungifaber (Sjöstedt, 1896)	83	67
		Isognathotermes gaigei (Emerson, 1928)	17	67
		Isognathotermes bulbifrons (Sjöstedt, 1924)	50	33
		Isognathotermes zenkeri (Desneux, 1904)	67	33
		Isognathotermes finitimus (Schmitz, 1916)	66	33
		Isognathotermes sp.1	33	0
		Isognathotermes sp.2	17	0
	Polyspathotermes (1)	*Polyspathotermes sulcifrons* (Wasmann, 1911)	50	67
	Mirotermes (1)	*Mirotermes hopes*		
	Thoracotermes (3)	*Thoracotermes macrothorax* (Sjöstedt, 1899)	17	0
		Thoracotermes sp.1	0	17
		Thoracotermes sp.2	0	17
	Nititermes (4)	*Nititermes berghei* (Emerson, 1960)	17	17
		Nititermes sankurensis (Wasmann, 1911)	50	67
		Nititermes orthognathus (Emerson, 1928)	50	17
		Nititermes sp.	17	0
	Noditermes (1)	*Noditermes lamanianus* (Sjöstedt, 1905)	17	17
	Procubitermes (2)	*Procubitermes* sp.	17	0
		Procubitermes wasmanni (Emerson, 1928)	17	17
	Mucrotermes (1)	*Mucrotermes osborni* Emerson, 1960	0	50
Termitinae (10)	*Fastigitermes* (1)	*Fastigitermes jucundus* (Sjöstedt, 1907)	33	17
	Furculitermes (1)	*Furculitermes winifredae* Emerson, 1960	50	0
	Lepidotermes (1)	*Lepidotermes goliathi* (Williams, 1954)	17	0
	Megagnathotermes (3)	*Megagnathotermes notandus* Silvestri, 1914	17	50
		Megagnathotermes sp.1	33	0
		Megagnathotermes sp.2	17	0
	Tuberculitermes (1)	*Tuberculitermes bycanistes* (Sjöstedt, 1905)	17	0
	Pericapritermes (1)	*Pericapritermes urgens* Silvestri, 1914	17	0
	Promirotermes (2)	*Promirotermes orthoceps* (Emerson, 1928)	0	17
		Promirotermes sp.	17	0
Amitermitinae (6)	*Microcerotermes* (6)	*Microcerotermes edentatus* Wasmann, 1911	33	50
		Microcerotermes fuscotibiallis (Sjöstedt, 1896)	33	33
		Microcerotermes pavus (Haviland, 1898)	33	67
		Microcerotermes progrediens Silvestri, 1914	33	67
		Microcerotermes silvestrianus Emerson, 1928	17	33
		Microcerotermes sp.1	0	17
	Acanthotermes (1)	*Acanthotermes acanthothorax* (Sjöstedt, 1898)	33	0

Macrotermitinae (30)	*Allodontotermes* (1)	*Allodontotermes* sp.1	17	0
	Ancistrotermes (2)	*Ancistrotermes crucifer* (Sjöstedt, 1897*)*	67	67
		Ancistrotermes sp.		
	Macrotermes (7)	*Macrotermes bellicosus* (Smeathman, 1781)	0	33
		Macrotermes lilljeborgi (Sjöstedt, 1896)	50	17
		Macrotermes mossambicus Hagen, 1853	0	0
		Macrotermes amplus (Sjöstedt, 1899)	67	33
		Macrotermes natalensis (Haviland, 1898)	33	17
		Macrotermes sp.	0	17
		Macrotermes vitrialatus (Sjöstedt, 1899)	0	33
	Microtermes (10)	*Microtermes calvus* Emerson, 1928	17	0
		Microtermes feae Silvestri, 1912	50	33
		Microtermes hopes	17	0
		Microtermes osborni Emerson, 1928	67	50
		Microtermes parvus	17	0
		Microtermes pusillus Silvestri, 1914	50	33
		Microtermes sp.1	17	50
		Microtermes sp.2	17	50
		Microtermes sp.3	50	33
		Microtermes sp.4	0	17
		Mirotermes hopes	17	0
	Odontotermes (4)	*Odontotermes lacustris* Harris, 1960	0	33
		Odontotermes mukimbunginis Sjöstedt, 1924	17	0
		Odontotermes sp.1	0	33
		Odontotermes stanleyvillensis (Emerson, 1928)	17	0
	Protermes (1)	*Protermes hirticeps S*jöstedt, 1924	17	50
	Pseudacanthotermes (2)	*Pseudacanthotermes militaris* (Hagen, 1858)	83	33
		Pseudacanthotermes spiniger (Sjöstedt, 1900)	50	0
	Synacanthotermes (1)	*Synacanthotermes acanthothorax*	17	0
Nasutitermitinae (14)	*Fulleritermes* (3)	*Fulleritermes coatoni* Sands, 1965	17	17
		Fulleritermes sp.	0	17
		Fulleritermes tenebricus (Silvestri, 1914)	33	17
	Nasutitermes (5)	*Nasutitermes diabolus* (Sjöstedt, 1907)	33	17
		Nasutitermes arborum (Smeathman, 1781)	33	50
		Nasutitermes fulleri Emerson, 1928	50	50
		Nasutitermes santschii	0	17
		Nasutitermes schoutedeni (Sjöstedt, 1924)	0	17
	Trinervitermes (6)	*Trinervitermes bettonianus* (Sjöstedt, 1905)	17	17
		Trinervitermes occidentalis (Sjöstedt, 1904)	17	33
		Trinervitermes rhodesiensis (Sjöstedt, 1911)	33	0
		Trinervitermes roseri	0	0
		Trinervitermes sp.	17	17
		Trinervitermes togoensis (Sjöstedt, 1899)	17	0
Sphaerotermitinae (1)	*Sphaerotermes* (1)	*Sphaerotermes sphaerothorax* (Sjöstedt, 1911)	50	50
Rhinotermitinae (4)	*Reticulitermes* (1)	*Reticulitermes* sp.	17	0
	Schedorhinotermes (3)	*Schedorhinotermes intermidius*	17	0
		Schedorhinotermes ptlorus (Sjöstedt, 1896)	0	17
		Schedorhinotermes sp.	0	17

MDNP: Mpem et Dim National Park; DDNP: Deng Deng National Park; Fo= Frequency of occurrence. The numbers into parenthesis in column 2 represent the numbers of species for each recorded genus.

III.1.3.2.3.2 Variation of termites' occurrence in the different habitat types

In DDNP, one species was commonly sampled (Fo≥20%; Table XXXIX) in the GF's termite community, namely *Macrotermes amplus* (Sjöstedt, 1899), while *Reticulitermes* sp. was the only common species sampled in MDNP's GF. In DDNP's GS, we recorded one common species, namely *Ancistrotermes crucifer* and *Pseudacanthotermes militaris* in MDNP’s GS. None of the species was common in NPF at DDNP, while, *Nititditermes sankurensis* was common in the MDNP’s NPF. A similar trend was observed in SF, Sw., and WS, though in DDNP’s WS, *Nititditermes orthognathus, Isognathotermes fungifaber,* and *Ancistrotermes crucifer* were most common. *Isognathotermes gaigai, Nititditermes sankurensis, Microcerotermes edentatus,* and *Polyspathotermes sulcifrons* were commonly sampled in Sl. in MDNP.

In DDNP’s termite community, the GF recorded two species considered to be less common (10% ≤ Fo≤ 20%) namely *Isognathotermes zenkeri* and *Microtermes osborni*. We recorded six species that were less commonly sampled in MDNP GF, including *Microcerotermes progrediens, Microcerotermes silvestrianus, Coxotermes* sp., *Microtermes* sp.1, *Nasutitermes fulleri,* and *Pseudacanthotermes spiniger.* For SF, *Isognathotermes zenkeri* and *Microtermes osborni* were uncommon in MDNP, while none of the species were less common in DDNP SF. *Furculitermes winifredae*, *Macrotermes amplus*, and *Fulleritermes tenebricus* in DDNP and *Trinervitermes occidentalis* and *Pseudacanthotermes militaris* in MDNP were considered less common in WS.

In DDNP termite communities, we recorded seven species in GF, 22 species in GS, 37 species in NPF, 25 species in SF, no species in SW, and eight species in WS that were uncommon sampled (Fo≤10%; Table XXXIX). In MDNP, we recorded 38 species in GF, 21 species in GS, 25 species in NPF, 27 species in SF, no species in Sl., no species in SW, and 19 species in WS that were rarely sampled in the termite communities.

Table XXXIX : Frequency of occurrence of termite species commonly and less commonly sampled in each habitat type except swamp and saltwork.

		DDNP					MDNP				
Sub-families	**Species**	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
	Number of samples →	300	300	300	300	300	150	150	300	300	150
	Microcerotermes edentatus	0	0	0	0	0	4.76	0	4.24	3.75	0
Amitermitinae	*Microcerotermes fuscotibiallis*		0	0	0	0	4.76	0	1.69	2.5	0
	Microcerotermes pavus	0	0	0	0	0	16.67	2.17	0	1.25	3.77
	Microcerotermes progrediens	0	0	0	0	0	16.67	2.17	2.54	3.75	7.55
	Microcerotermes silvestrianus	0	0	0	0	0	2.38	0	5.08	7.5	0
	Microcerotermes sp.1	0	0	0	0	0	2.38	0	1.69	0	0
Apicotermitinae	*Coxotermes* sp.	**0**	**0**	**0**	**0**	**0**	19.05	**0**	**0**	**0**	**1.89**
	Crenetermes mixtus	0	0	0.87	0	0	0	0	0	0	0
Cubitermitinae	*Isognathotermes ugandensis*	0	0	3.48	1.11	0	0	4.35	0	0	1.89
	Isognathotermes fungifaber	6.25	2.5	3.48	5.56	15	9.52	0	9.32	6.25	15.09
	Isognathotermes congoensis	0	3.75	1.74	0	0	9.52	4.35	5.93	0	3.77
	Isognathotermes gaigei	0	0	0	2.22	0	0	8.7	0	0	3.77
	Isognathotermes bulbifrons	0	0	6.09	1.11	0	0	0	0	0	0
	Isognathotermes zenkeri	18.7	1.25	6.09	5.56	0	0	0	7.63	15	0
	Isognathotermes finitimus	6.25	3.75	6.09	4.44	5	2.38	0	2.54	7.50	0
	Isognathotermes sp.1	0	0	0	1.11	5	2.38	0	0	0	0

	Isognathotermes sp.2	0	0	0.87	0	0	0	0	0	0	0
	Polyspathotermes sulcifrons	0	0	3.48	2.22	0	2.38	2.17	0.85	0	7.55
	Mirotermes hopes	0	0	0	0	0	2.38	0	0	0	0
	Nitiditermes orthognathus	6.25	2.5	0	0	15	0	0	0.85	0	0
	Nitiditermes sankurensis	0	0	5.22	4.44	0	0	2.17	20.34	3.75	0
	Nitiditermes berghei	0	0	0.87	0	0	0	0	0	3.75	0
	Nitiditermes sp.	0	0	0.87	0	0	0	0	0	0	0
	Noditermes lamanianus	0	0	2.61	0	0	0	2.17	0	0	0
	Procubitermes sp.	0	2.5	0	0	0	0	0	0	0	0
	Procubitermes wasmani	0	0	0	0	0	0	0	1.74	0	0
	Mucrotermes osborni	0	0	0	0	0	0	0	0	0	0
	Thoracotermes macrothorax	0	0	0.87	0	0	2.38	0	0	0	0
	Thoracotermes sp.1	0	0	0	0	0	0	0	0	0	1.89
	Thoracotermes sp.2	0	0	0	0	0	0	2.17	0	0	0
Coptotermitinae	*Coptotermes sjostedti*	0	0	0	0	0	1.89	0	0	0	0
Macrotermitinae	*Acanthotermes acanthothorax*	0	0	7.83	5.56	0	0	0	0	0	0
	Allodontotermes sp.1	0	0	0.87	0	0	2.38	0	0	0	0
	Ancistrotermes crucifer	6.25	38.7	0	0	20	2.38	8.7	0.85	1.25	5.66
	Ancistrotermes sp.1	0	5.01	0	0	0	7.14	0	0	0	0
	Macrotermes bellicosus	0	0	0	0	0	7.14	4.35	0	0	5.66
	Macrotermes lilljeborgi	6.25	0	0.87	2.22	0	2.38	0	2.54	0	0
	Macrotermes mossambicus	0	0	0	0	0	2.38	0	0	0	0
	Macrotermes amplus	25	1.25	0	3.33	10	2.38	0	5.93	1.25	0
	Macrotermes natalensis	0	1.25	0	0	5	2.38	2.17	0	0	0
	Macrotermes sp.	0	0	0	0	0	0	2.17	0	0	0
	Macrotermes vitrialatus	0	0	0	0	0	0	2.17	0	0	5.66
	Microtermes feae	0	0	5.22	3.33	0	0	0	0.85	0	0
	Microtermes hopes	0	0	0	3.33	0	2.38	0	0	0	0
	Microtermes osborni	12.5	1.25	6.96	6.67	0	2.38	0	4.24	11.25	1.89
	Microtermes pusillus	0	0	2.61	5.56	0	0	0	2.54	5	0
	Microtermes parvus		3.75	0		10		0		3.75	
	Microtermes calvus	0	0	0.87	0	0	11.9	0	0	0	0
	Microtermes sp.1	0	0	3.48	0	0	11.9	0	5.93	3.75	1.89
	Microtermes sp.2	0	0	1.74	0	0	0	0	0.85	3.75	1.89
	Microtermes sp.3	0	1.25	0	1.11	5	0	0	2.54	1.25	0
	Microtermes sp.4	0	0	0	0	0	0	0	0	1.25	0
	Odontotermes sp.1	0	0	0	0	0	0	0	0.85	3.75	0
	Odontotermes lacustris	0	0	0.87	0	0	11.9	0	0	0	0
	Odontotermes mukimbunginis	0	0	3.48	0	0	11.9	0	5.93	3.75	1.89
	Odontotermes stanleyvillensis	0	0	1.74	0	0	0	0	0.85	3.75	1.89
	Protermes hirticeps	0	0	0	1.11	0	7.14	0	1.69	1.25	1.89
	Pseudacanthotermes militaris	6.25	7.5	4.35	2.22	5	7.14	21.74	0	0	13.21
	Pseudacanthotermes spiniger	6.25	3.75	0	0	5	16.67	0	0	0	0
	Synacanthotermes acanthothorax	1.11	0	0	0	0	0	0	0	0	0
Nasutitermitinae	*Fulleritermes coatoni*	0	1.25	0	0	0	0	2.17	0	0	0
	Fulleritermes sp.	0	0	0	0	0	0	0	0	0	1.89
	Fulleritermes tenebricus	0	8.75	0	0	10	0	2.17	0	0	0
	Nasutitermes diabolus	0	0	0	0	0	2.38	0	0	0	1.89
	Nasutitermes arborum	0	0	1.74	3.33	0	9.52	6.52	0	2.5	1.89
	Nasutitermes fulleri	0	0	8.7	5.56	0	11.9	6.52	0.85	2.5	0
	Nasutitermes santschii	0	0	0	0	0	4.76	0	0	0	3.77
	Nasutitermes schoutedeni	0	0	0	0	0	0	0	1.69	0	0
	Trinervitermes bettonianus	0	1.25	0	0	0	0	2.17	0	0	0
	Trinervitermes occidentalis	0	0	0	1.11	0	0	6.52	0	0	11.32
	Trinervitermes rhodesiensis	0	1.25	0	0	0	2.38	0	0	0	0

	Trinervitermes roseri	0	0	0	0	0	2.38	0	0	0	0
	Trinervitermes sp.	0	0	1.74	0	0	2.38	2.17	0	0	0
	Trinervitermes togoensis										
Rhinotermitinae	*Schedorhinotermes intermidius*	0	0	0	0	5	0	0	0	0	0
	Schedorhinotermes putorus	0	0	0	0	0	2.38	0	0	2.5	0
	Schedorhinotermes sp.	0	0	0	0	0	2.38	0	0	0	0
	Reticulitermes sp.	0	0	1.74	0	0	35.71	0	0	0	0
Sphaerotermitinae	*Sphaerotermes sphaerothorax*	**0.87**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Termitinae	*Fastigitermes jucundus*	0	0.77	3.33	0	0	0	1.25	1.41	1.29	0
	Furculitermes winifredae	0	3.75	0	0	10	0	0	0	0	0
	Lepidotermes goliathi	3.75	0	0	0	0	3.39	3.75	3.75	0	3.32
	Megagnathotermes notandus	0	0	0	5	0	0	0	0	3.75	0
	Megagnathotermes sp.1	9.25	0	0	0	2.37	0	0	3.75	0	0
	Megagnathotermes sp.2	0	0.77	0	0	2.37	0	0	0	0	0
	Pericapritermes urgens	0	0	0.87	0	0	0	0	0	0	0
	Promirotermes orthoceps	0	0	0	0	0	2.38	0	0	3.75	0
	Promirotermes sp.	1.74	0	0	0	0	0	0	0	0	0
	Tuberculitermes bycanistes	0	00	0	0	0	0	1.25	0	0	0

Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna. Species with Fo>20% were considered to be common and those with 10% ≤ Fo≤ 20% were considered to be less common and species with Fo<10% were considered uncommon.

III.1.3.2.3.3 Seasonal variation of termites' occurrence

During the dry season, two species recorded were common (with Fo≥50%; Table XL) in DDNP's termite community, namely *Isognathotermes zenkeri* and *Pseudacanthotermes militaris*. In the MDNP dry season termite community, 18 species were common. These include seven species from the genus *Isognathotermes*, three *Microcerotermes*, four *Microtermes* species, and also *Odontotermes lacustris, Odontotermes* sp.1, *Nasutitermes arborum*, and *Nasutitermes fulleri.* Six termite species were common in DDNP's termite community during the rainy season, including *Iso. fungifaber, Nitiditermes orthognathus, Iso. schmidti, Ancistrotermes crucifer, Macrotermes lilljeborgi*, and *Macrotermes amplus,* while eight species were common in MDNP's termite community during the rainy season, including several species of the genus *Isognathotermes* such as *Iso. congoensis* (Emerson, 1928), *Iso. fungifaber, Nitiditermes sankurensis, Polyspathotermes sulcifrons*, and *Microcerotermes parvus, Microcerotermes progrediens, Ancistrotermes crucifer, Microtermes osborni* and *Microtermes* sp.1.

Eighteen termite species were less common in DDNP's termite community with 25%≤Fo≤50% in the dry season, including six species from the genus *Isognathotermes*; two *Microcerotermes,* four *Microtermes* species (see Table XL), and also *Ancistrotermes crucifer, Nasutitermes diabolus, Nasutitermes fulleri, Trinervitermes rhodesiensis*, and *Sphaerotermes sphaerothorax*. While 14 species were less commonly recorded in MDNP, including two

Isognathotermes, two *Microcerotermes*, two *Microtermes*, two *Macrotermes* species, *Coptotermes sjostedti*, *Procubitermes wasmani*, *Nitiditermes berghei*, *Promirotermes orthoceps*, *Ancistrotermes crucifer*, *Protermes hirticeps*, and *Fastigitermes jugondus.* Eighteen species were less commonly recorded in the DDNP termite community during the rainy season, including four *Isognathotermes*, three *Microcerotermes*, three *Microtermes* species, *Furculitermes winifredae*, *Acanthotermes acanthothorax*, *Macrotermes natalensis*, *Pseudacanthotermes spiniger*, *Fulleritermes tenebricus*, *Nasutitermes arborum*, *Nasutitermes fulleri*, and *Fastigitermes jugondus.* The same number of species were less commonly sampled in MDNP during the rainy season, including three *Isognathotermes*, four *Microcerotermes*, five *Macrotermes*, three *Nastitermes* species, *Microtermes* sp.2, *Protermes hirticeps*, *Pseudacanthotermes militaris*, and *Trinervitermes occidentalis.*

During the dry season, 26 species in the DDNP and three species in MDNP were considered to be uncommonly (rarely) collected in the termite communities (Fo≤25%), while in the rainy season, 31 species in the DDNP and 28 species in MDNP with Fo≤25% were rarely sampled (see Table XL).

Table XL: Frequency of occurrence of termite species sampled during different season in each national park

		DDNP		MDNP	
Sub-families	**Species**	**Dry**	**Rainy**	**Dry**	**Rainy**
	Number of samples →	**1050**	**1050**	**450**	**1050**
Coptotermitinae	*Coptotermes sjostedti*	0	0	33	0
Apicotermitinae	*Coxotermes* sp.	0	0	0	17
Cubitermitinae	*Crenetermes mixtus*	0	20	0	0
	Isognathotermes ugandensis	50	20	67	33
	Isognathotermes fungifaber	17	60	67	67
	Isognathotermes congoensis	33	0	0	67
	Isognathotermes gaigei	17	20	33	50
	Isognathotermes bulbifrons	50	20	67	0
	Isognathotermes zenkeri	67	0	67	17
	Isognathotermes finitimus	50	100	100	50
	Isognathotermes sp.1	0	40	0	17
	Isognathotermes sp.2	0	20	0	0
	Polyspathotermes sulcifrons	50	20	67	67
	Procubitermes sp.	0	20	0	0
	Procubitermes wasmani	17	0	33	0
	Mirotermes hopes	0	0	0	17
	Mucrotermes osborni	0	0	17	0
	Nitiditermes berghei	0	20	33	0
	Nitiditermes sankurensis	50	40	67	67
	Nitiditermes orthognathus	0	60	0	17
	Nitiditermes sp.	0	20	0	0
	Noditermes lamanianus	0	20	0	17
	Thoracotermes macrothorax	0	20	0	17
	Thoracotermes sp.1	0	0	0	17
	Thoracotermes sp.2	0	0	0	17
	Microcerotermes edentatus	17	40	67	50
	Microcerotermes fuscotibiallis	33	0	33	50
	Microcerotermes pavus	33	40	33	67

Amitermitinae	*Microcerotermes progrediens*	17	40	67	83
	Microcerotermes silvestrianus	17	20	67	50
	Microcerotermes sp.	0	0	0	17
Macrotermitinae	*Acanthotermes acanthothorax*	17	40	0	0
	Allodontotermes sp.1	0	20	0	0
	Ancistrotermes crucifer	50	60	33	83
	Ancistrotermes sp.	17	20	0	0
	Macrotermes bellicosus	0	0	0	50
	Macrotermes lilljeborgi	0	60	33	17
	Macrotermes mossambicus	0	0	0	17
	Macrotermes amplus	0	80	33	33
	Macrotermes natalensis	0	40	0	33
	Macrotermes sp.	0	0	0	17
	Macrotermes vitrialatus	0	0	0	33
	Microtermes calvus	17	0	0	0
	Microtermes feae	33	40	67	17
	Microtermes hopes	0	20	0	0
	Microtermes osborni	33	40	67	67
	Microtermes parvus	17	0	0	0
	Microtermes pusillus	50	40	67	17
	Microtermes sp.1	0	20	0	67
	Microtermes sp.2	17	0	33	33
	Microtermes sp.3	33	20	67	17
	Microtermes sp.4	0	0	33	0
	Odontotermes lacustris	0	0	67	0
	Odontotermes mukimbunginis	17	0	0	0
	Odontotermes sp.1	0	0	67	0
	Odontotermes stanleyvillensis	17	0	0	0
	Pseudacanthotermes spiniger	17	40	0	0
	Synacanthotermes acanthothorax	17	0	0	0
	Protermes hirticeps	0	20	33	33
	Pseudacanthotermes militaris	67	1	0	50
Nasutitermitinae	*Fulleritermes coatoni*	0	20	0	17
	Fulleritermes sp.	0	0	0	17
	Fulleritermes tenebricus	17	40	0	17
	Nasutitermes diabolus	33	0	0	17
	Nasutitermes arborum	17	40	67	50
	Nasutitermes fulleri	50	40	67	33
	Nasutitermes santschii	0	0	0	33
	Nasutitermes schoutedeni	0	0	0	17
	Trinervitermes bettonianus	17	20	0	17
	Trinervitermes occidentalis	0	20	0	33
	Trinervitermes rhodesiensis	33	0	0	0
	Trinervitermes roseri	0	0	0	17
	Trinervitermes sp.	0	20	0	17
	Trinervitermes togoensis	17	20	0	0
Rhinotermitinae	*Schedorhinotermes intermidius*	0	20	0	0
	Schedorhinotermes putorus	0	0	0	17
	Schedorhinotermes sp.	0	0	0	17
	Reticulitermes sp.	0	0	20	0
Sphaerotermitinae	*Sphaerotermes sphaerothorax*	50	0	1	0
Termitinae	*Pericapritermes urgens*	17	0	0	0
	Fastigitermes jucundus	17	40	33	0
	Furculitermes winifredae	17	40	0	0
	Lepidotermes goliathi	17	0	0	0
	Tuberculitermes bycanistes	0	20	0	0
	Megagnathotermes notandus	17	20	1	0
	Megagnathotermes sp.1	17	20	0	0
	Megagnathotermes sp.2	17	0	0	0
	Promirotermes orthoceps	0	0	33	0
	Promirotermes sp.	0	20	0	17

MDNP: =Mpem et Dim National Park; DDNP = Deng Deng National Park; Fo= Frequency of Occurrence

II.1.3.2.4 Similarity of termites' communities in habitat types

III.1.3.2.4.1 Proportion of termite species shared between habitat typess

Based on the proportion of shared species, in DDNP, all the habitat types have in common at least one species with a maximum of 21 species (28.38%) shared between SF and NPF and a minimum of 1 species (1.35%) shared between Sw. and GF, GS, WS (see Table XLI).

Table XLI: Relative proportion of termite species shared between habitat types in Deng Deng National Park

GF	GS	NPF	SF	Sw.	WS	
	11 (14.86)	8 (10.81)	12 (16.22)	1 (1.35)	11 (14.86)	GF
		11 (14.86)	13 (17.57)	1 (1.35)	**15 (20.27)**	GS
			21 (28.38)	2 (2.7)	7 (9.46)	NPF
				3 (4.05)	12 (16.22)	SF
					1 (1.35)	Sw.
						WS

Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; GS=Grassland Savanna; Sw.= Swamp. The numbers in parentheses are the percentages of species shared between the habitat types based on the total number of species sampled.

In MDNP, except the pairs between SW and WS, GF, GS, and Sl. which have no species in common, all the other habitat types shared at least one species. The SF and NPF have in common the greatest number of termite species (27 species; 40.7% of all the species sampled; Table XLII).

Table XLII: Relative proportion of termite species shared between habitat types in Mpem et Djim National Park

GF	GS	NPF	SF	Sl.	Sw.	WS	
	10 (15.15)	**12 (18.18)**	11 (16.67)	2 (3.03)	0 (0)	**12 (18.18)**	GF
		9 (13.64)	7 (10.61)	3 (4.55)	0 (0)	**12 (18.18)**	GS
			27 (40.91)	4 (6.06)	3 (4.55)	**12 (18.18)**	NPF
				2 (3.03)	3 (4.55)	10 (15.15)	SF
					0 (0)	2 (3.03)	Sl.
						0 (0)	Sw.
							WS

Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; Sl.=Saltworks; GS=Grassland Savanna; Sw.= Swamp. The grey color denotes a higher proportion of species shared between habitats. The numbers into parenthesis are the percentages of species shared between different habitat types based on the total number of species sampled.

III.1.3.2.4.2 Similarity of specific composition of habitat types

In DDNP the highest similarity of termite community composition was observed between GS and WS Cn=0.934, followed by NPF and SF (Cn=0.795) then GS, GF and WS, GF (Cn=0.575 and Cn=0.591), respectively. A higher dissimilarity was recorded in termite community between SW and WS, GS (Cn=0.038 and Cn=0.043 respectively; Table XLIII).

Table XLIII: Bray-Curtis' dissimilarity indices comparing pairs of habitat types in Deng Deng National Park

GS	NPF	SF	Sw.	WS	
0.575	0.409	0.444	0.315	0.591	GF
	0.128	0.154	0.043	**0.934**	GS
		0.795	0.272	0.072	NPF
			0.234	0.156	SF
				0.038	Sw.
					WS

The numbers in bold denote a higher Bray-Curtis index value. The greater are the index values (near 1) more similar are the pairs of habitats. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; SL=Saltworks; GS=Grassland Savanna; SW= Swamp.

In MDNP, the termite communities in SF and NPF were the most similar (Cn=0.707) in terms of species composition, followed by GS and WS (Cn=0.681), and the high dissimilarity was recorded between WS and GF and GS and SW. A higher dissimilarity of termite community composition was between SW and GF, GS, WS (Cn=0; see Table XLIV).

Table XLIV: Bray-Curtis' dissimilarity indices comparing pairs of habitat types in Mpem et Djim National Park

GF	NPF	SF	Sl.	Sw.	WS	
0.424	0.3	0.314	0.075	0	**0.601**	GF
	0.117	0.102	0.194	0	**0.681**	GS
		0.707	0.348	0.233	0.256	NPF
			0.102	0.239	0.184	SF
				0	0.161	Sl.
					0	Sw.
						WS

The numbers in bold denote a higher Bray-Curtis index value. The greater are the index values (near 1) more similar are the pairs of habitats. Habitat codes are GF= Gallery Forest; NPF= Near Primary Forest; WS=Woodland Savanna; SL=Saltworks; GS=Grassland Savanna; SW= Swamp.

III.1.4 Pangolin diet composition

III.1.4.1 White-bellied pangolin diet composition

III.1.4.1.1 Stomach and scat components

A total of 13 stomach contents each weighing 72.6 grams were analyzed. The stomach contained ant and termite undigested individuals (90% of total weight) and body parts of insects (Fig. 50 a,b,c). These included termite and ant heads, ant legs, ant abdomens, ant thorax (5.01%), bristles (<1%), ant egg shells (3.07%), clay (termites' mounds; (1.02%), sands (2.05%), plant matter (<1%), stones (<1%), and snail shells (<1%). Other invertebrates (<1%) were also recorded, including Coleoptera and Hemiptera, Diptera, Arachnida, Mites, and Nemathelminths.

One white-bellied pangolin fecal sample weighing 50 grams in dry matter weight (Fig. 50d), the scat from the white-bellied pangolin contained insect body parts, including termite and ant heads, legs, abdomen, thorax that are difficult to quantify (see Fig. 50e). This sampled was precluded from all data qualitative and quantitative analysis.

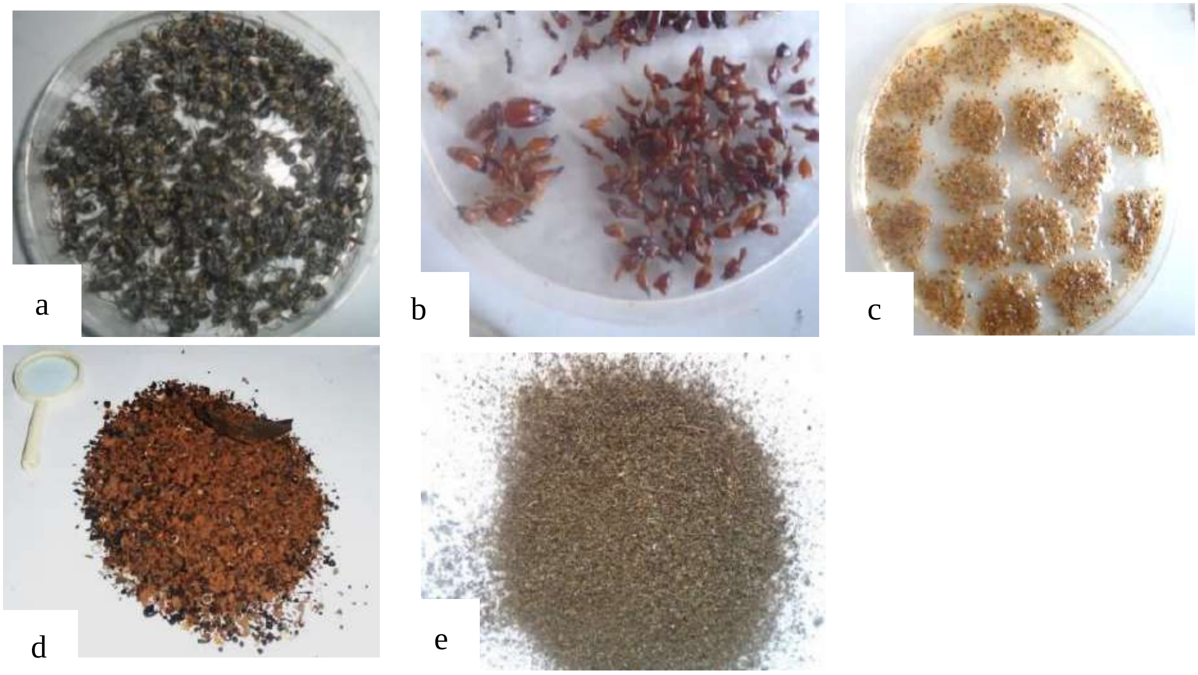

Figure 50: White-bellied pangolin stomach and scat contents: a) ant species entire body; b) large size termite species entire body isolated with hand-sorting; c) small size termite sorted with hand-stereomicroscope, d) very old unidentified scat showing mixed sand, stone and plant matter, and remaining insect body parts; e) result of fresh scat analysis showing mixed fragments of legs and abdomen of ants unidentifiable.

III.1.4.1.1.1 Relative abundance of pangolin stomach invertebrate's fauna

A total of 165,161 invertebrate individuals were recorded in 13 pangolin specimens, including 165,000 Arthropoda belonging to six Orders, including Blattodea (65,482 individuals; 39.65%) and Hymenoptera (99,651 individuals; 60.34%), which were commonly recorded. Coleoptera (6 individuals; <1%), Hemiptera (19 individuals; <1%), and Diptera (2 individuals each; <1%) were rarely recorded. Mite (rare) and Nemathelminths (frequent) might be ecto-parasites and endo-parasites of white-bellied pangolins respectively (Table XLV). Nemathelminths are transmitted through ants, an intermediary host. Arachnida was likely a predator of insect preys eaten by pangolins.

Table XLV: Absolute and relative abundances, frequency of occurrence of invertebrate's fauna from the white-bellied pangolin stomachs. Number of samples (N=13)

	Stomach content	Ar	Fo (%)	Category	Roles
Orders	Mites	0 (1)	7.69	Acl	Ecto-parasites of pangolins
	Blattodea	39.65 (65482)	100	C	Preys of pangolins
	Coleoptera	0 (6)	23.08	Acl	Necrophageous
	Diptera	0 (1)	7.69	Acl	Undetermined
	Hemiptera	0.01 (19)	30.77	A	Predators of ants and termites
	Hymenoptera	60.34 (99651)	100	C	Preys of pangolins and host of parasites
Class	**N**emathelminths	0.1 (160)	84.62	C	Endo-parasites of pangolins
	Arachnida	0 (1)	7.69	Acl	Predators of ants and termites
Total		**100 (165161)**			

Ar= relative abundance; Fo= frequency of occurrence; C= Constant or common prey/consumed preferentially; A= Accessory or Uncommon prey/secondarily consumed; Acl= Accidental or less common prey /rarely consumed prey

III.1.4.1.1.2 Relative importance of ant and termite subfamilies in white-bellied pangolin diet

Except for Dorylinae and Ponerinae (RI=0.05) rarely eaten, all ant subfamilies identified were preferentially eaten (commonly) by white-bellied pangolins. Myrmicinae subfamily has the highest relative importance (RI=31.81) dominating the other subfamilies with 52,538 individuals and 44 species, followed by Formicinae (RI=18.25; 30,148 individuals; 32 species). Ponerinae (RI=0.05; 124 individuals; 12 species) and Dolichoderinae (RI=0.73; 1,424 individuals; with 9 species) were the least common subfamilies, while Dorylinae recorded five species (Table XLVI).

Two termite families, Rhinothermitidae and Termitidae, were preferentially eaten by the white-bellied pangolins examined. Macrotermitinae subfamily dominates the other subfamilies, being the most frequently represented in the samples (RI=16.11; 26,607 individuals; 19 species) followed by Rhinotermitinae and Spharotermitinae. They had 435, 641, and 91 individuals and three, one, and one species, respectively. Coptotermitinae (RI=0.12; 435 individuals; three species) were uncommon (RI=0.12). Cubitermitinae and Termitinae were the least common subfamily recorded (Table XLVI).

Table XLVI: Relative importance of the main insect families and subfamilies from white-bellied pangolin stomachs. Number of samples (N=13)

Orders	Families	Sub-families	Ar	Fo (%)	RI	Prey Category
Blattodea			39.65 (65482)	100	39.65	C
	Rhinotermitidae		0.27 (439)	53.85	0.14	A
		Coptotermitinae (1)	0 (91)	30.77	0.12	A
		Rhinotermitinae (3)	0.26 (435)	46.15	0.12	A
	Termitidae		39.38 (65043)	100	39.38	C
		Amitermitinae (6)	0.05 (87)	23.08	0.01	Acl
		Cubitermitinae (3)	0.01 (20)	30.77	0	Acl
		Macrotermitinae (18)	16.11 (26607)	100	16.11	C
		Sphaerotermitinae (1)	0.39 (642)	30.77	0.12	A
		Termitinae (1)	0 (1)	7.69	0	Acl
		Nasutermitinae (3)	20.8 (34355)	92.31	19.2	C
Hymenoptera	Formicidae		60.34 (99650)	100	60.34	C
		Dolichoderinae (9)	0.86 (1424)	84.62	0.73	C
		Dorylinae (5)	0.1 (162)	53.85	0.05	Acl
		Formicinae (35)	18.25 (30148)	100	18.25	C
		Myrmicinae (44)	31.81 (52538)	100	31.81	C
		Ponerinae (12)	0.08 (124)	69.23	0.05	Acl

Ar= relative abundance; Fo = frequency of occurrence; C = Constant or common prey/consumed preferentially; A = Accessory or uncommon prey/secondarily consumed; Acl = Accidental or less common prey/rarely eaten prey. The numbers into parenthesis in column 3 (sub-families) represent the numbers of species for each genus recorded and in column 4 are absolute abundance.

III.1.4.1.1.3 Relative importance of ant genera

Twenty-four ant genera (~92.0% of sampled genera) were recorded in 13 pangolin stomach contents, and eight genera (~35.8%; see Table XLVII) were preferentially eaten by white-bellied pangolin individuals, including *Crematogaster* (RI=17.28; 28,537 individuals; 20 species) followed by *Camponotus* (RI=5.53; 9,128 individuals; 15 species); *Leptogenys* (RI=0.05; 124 individuals; 12 species); *Pheidole* (RI=10.51; 18,805 individuals; 11 species), *Polyrachis* (RI=0.84; 1,506 individuals; eight species), *Anoplolepis* (RI=8.56; 18,380 individuals; two species), *Formicidae gen* (3) (RI=1.54; 3,669 individuals; three species), and *Monomorium* (RI=1.01; 3,621 individuals; four species).

Five genera (21.73%) were secondarily eaten preys of white bellied pangolins (0.1<RI≤0.5). These included *Tapinoma* (554 individuals; three species), *Technomyrmex* (754 individuals; 3 species), *Dorylus* (162 individuals; 5 species), and *Lepisiota* (778 individuals; 2 species), *Tetramorium* (681 individuals; 4 species). Ten genera were rarely eaten by white-bellied pangolin (see Table XLVII).

Table XLVII: Relative importance of the Hymenoptera main subfamilies and genera from white-bellied pangolin and their species richness into brackets

Families	Subfamilies/Genera	Ar	Fo	RI	Prey Category
Formicidae		60.34 (99650)	100	60.34	C
	Dolichoderinae (9)	**0.86 (1424)**	**84.62**	**0.73**	**C**
	Axinidris (3)	0.07 (123)	23.08	0.02	Acl
	Tapinoma (3)	0.34 (554)	53.85	0.18	A
	Technomyrmex (3)	0.45 (747)	53.85	0.24	A
	Dorylinae (5)	**0.1 (162)**	**53.85**	**0.05**	**Acl**
	Dorylus (5)	0.1 (162)	53.85	0.05	A
	Formicidae sbfam (4)	**2.97 (4911)**	**69.23**	**2.06**	**C**
	Formicidae gen (4)	2.22 (3669)	69.23	1.54	C
	Formicinae (31)	**18.25 (30148)**	**100**	**18.25**	**C**
	Anoplolepis (2)	11.13 (18380)	76.92	8.56	C
	Camponotus (15)	5.53 (9128)	100	5.53	C
	Cataulacus (2)	0.07 (111)	15.38	0.01	Acl
	Lepisiota (2)	0.47 (778)	30.77	0.14	A
	Polyrachis (8)	0.91 (1506)	92.31	0.84	C
	Pseudolasius (1)	0.15 (244)	23.08	0.03	Acl
	Tapinoleplis (1)	0 (1)	7.69	0	Acl
	Myrmicinae (44)	**31.81 (52538)**	**100**	**31.81**	**C**
	Cardiocondyla (1)	0.5 (820)	15.38	0.08	Acl
	Cataulacus (1)	0.04 (74)	23.08	0.01	Acl
	Crematogaster (20)	17.28 (28535)	100	17.28	C
	Monomorium (4)	2.19 (3621)	46.15	1.01	C
	Myrmicaria (1)	0 (1)	7.69	0	Acl
	Phasmomyrmex (1)	0 (1)	7.69	0	Acl
	Pheidole (11)	11.39 (18805)	92.31	10.51	C
	Tetramorium (4)	0.45 (681)	38.46	0.16	A
	Ponerinae (12)	**0.08 (124)**	**69.23**	**0.05**	**Acl**
	Anochetus (1)	0 (1)	7.69	0	Acl
	Hypoponera (3)	0.01 (13)	30.77	0	Acl
	Leptogynys (6)	0.06 (106)	61.54	0.04	Acl
	Ondontomachus (1)	0 (1)	7.69	0	Acl
	Ponera (1)	0 (3)	7.69	0	Acl

Ar= relative abundance; Fo= frequency of occurrence; RI=relative importance of prey; C= Constant or common prey/consumed preferentially; A= Accessory or uncommon prey/ secondarily consumed; Acl= Accidentally or less common prey/rarely eaten, Sbfam= Subfamily; gen= genus. The numbers into parentheses in column 2 represent the numbers of species for each recorded genus.

III.1.4.1.1.4 Relative importance of termite genera

Eighteen termite genera (~57.14% of sampled genera) were recorded in 13 pangolin stomach contents. Five genera (~25.0% of eaten genera) were preferentially eaten by white-bellied pangolins, including *Nasutitermes* (RI=17.07; 30,544 individuals; two species) followed by *Pseudacanthotermes* (RI=10.3 18,124 individuals; one species); *Odontotermes* (RI=0.74; 1,998 individuals; eight species), and *Macrotermes* (RI=2.63; 5,656 individuals; four species).

Four other genera were secondarily eaten by white bellied pangolins (0.1<RI≤0.5), including *Sphaerotermes* (642 individuals; one species), *Schedorhinotermes* (435 individuals; 2 species), *Acanthotermes* (303 individuals; one species), *Trinervitermes* (3,810 individuals; one species). Nine genera were rarely eaten by white-bellied pangolin (see Table XLVIII).

Table XLVIII: Relative importance of the Blattodea main subfamilies and genera from white-bellied pangolin and their species richness into brackets.

Families	**Subfamilies/Genera**	**Ar**	**Fo (%)**	**RI**	**Prey category**
Rhinotermitidae (3)		0.27 (439)	53.85	0.14	C
	Coptotermitinae (1)	**0.05 (91)**	**30.77**	**0.1**	**A**
	Coptotermes (1)	0 (4)	23.08	0	Acl
	Rhinotermitinae (2)	**0.26 (435)**	**46.15**	**0.12**	**A**
	Schedorhinotermes (2)	0.26 (435)	46.15	0.12	A
Termitidae (36)		39.38 (65043)	100	39.38	C
	Amitermitinae (3)	**0.05 (87)**	**23.08**	**0.01**	**Acl**
	Microcerotermes (3)	0.05 (84)	23.08	0.01	Acl
	Cubitermitinae (2)	**0.01 (20)**	**30.77**	**0**	**Acl**
	Isognathotermes (1)	0.01 (18)	30.77	0	Acl
	Ophiotermes (1)	0 (2)	7.69	0	Acl
	Macrotermitinae (19)	**16.11 (26607)**	**100**	**16.11**	**C**
	Acanthotermes (1)	0.18 (303)	38.46	0.07	A
	Allodontotermes (1)	0.02 (29)	15.38	0	Acl
	Macrotermes (4)	3.42 (5656)	76.92	2.63	C
	Microtermes (2)	0 (5)	23.08	0	Acl
	Odontotermes (8)	1.21 (1998)	61.54	0.74	C
	Protermes (1)	0.07 (109)	23.08	0.02	Acl
	Pseudacanthotermes (1)	10.97 (18124)	92.31	10.13	C
	Nasutermitinae (3)	**20.8 (34355)**	**92.31**	**19.2**	**C**
	Nasutitermes (2)	18.49 (30545)	92.31	17.07	C
	Trinervitermes (1)	2.31 (3810)	7.69	0.18	A
	Sphaerotermitinae (1)	**0.39 (642)**	**30.77**	**0.12**	**A**
	Sphaerotermes (1)	0.39 (642)	30.77	0.12	A
	Termitinae (1)	**0 (1)**	**7.69**	**0**	**Acl**
	Termitidae sbfam (4)	**1.97 (3250)**	61.54	1.21	C
	Termitidae gen (4)	**1.59 (2620)**	61.54	0.98	C
	Pericapritermes (1)	0 (1)	7.69	0	Acl

Ar= relative abundance; Fo= frequency of occurrence; RI=relative importance of prey; C= Constant or common prey/consumed preferentially; A= Accessory or uncommon prey/ secondarily consumed; Acl= Accidentally or less common prey/rarely eaten; Sbfam= Subfamily; gen= genus. The numbers into parentheses in column 1,2 represent the numbers of species for each recorded genus.

III.1.4.1.1.5 Ant species eaten by white-bellied pangolins

Overall, 105 ant species were recorded in 13 pangolin stomach contents comprising 4 alate morphospecies. This number of ants represents 72.91% of all actual preys and 91.81% of potential ant prey species sampled in habitats. Ten species (6.94% of preys eaten) were preferentially eaten by white-bellied pangolins, including *Anoploepis tenella* (RI=4.22; 9,061 individuals) followed by

Anoplolepis carinata (RI= 0.87; 9,124 individuals), *Camponotus chapini* (RI=2.58; 5,532 individuals), *Polyrachis militaris* (RI=0.64; 1,243 individuals), *Crematogaster acis* (RI=4.35; 8,500 individuals), *Crematogaster concava* (RI=2.12; 6,501 individuals), *Pheidole megacephala* (RI=4.11; 9,795 individuals), *Pheidole minima* (RI=0.93; 3,344 individuals), *Formicidae* sp.2 (RI=2.06; 8,851 individuals), and *Camponotus flavomarginatus* (RI=0.97; 1,735 individuals). Figure 69 shows some photos of ant species preferentially eaten by the white-bellied pangolins (appendix 5).

Seven ant species (4.86% of actual preys) were secondarily eaten by white-bellied pangolins (0.1<RI≤0.5), including *Crematogaster gabonensis* (1,960 individuals), *Monomorium* sp.1 (3,384 individuals), *Pheidole albidula* (1,513 individuals), *Pheidole* sp.2 (642 individuals), *Crematogaster* (*Oxygyne*) sp.1 (4,868 individuals), *Camponotus maculatus* (541 individuals), and *Camponotus brutus* (428 individuals) (Table XLIX). Eighty-eight ant species (61.11% of all actual preys) were rarely eaten RI≤0.1 by white-bellied pangolins (see appendix 5). Figure 51 shows the number of ant and termite prey species commonly, less commonly and uncommonly recorded in the stomach contents of white-bellied pangolins.

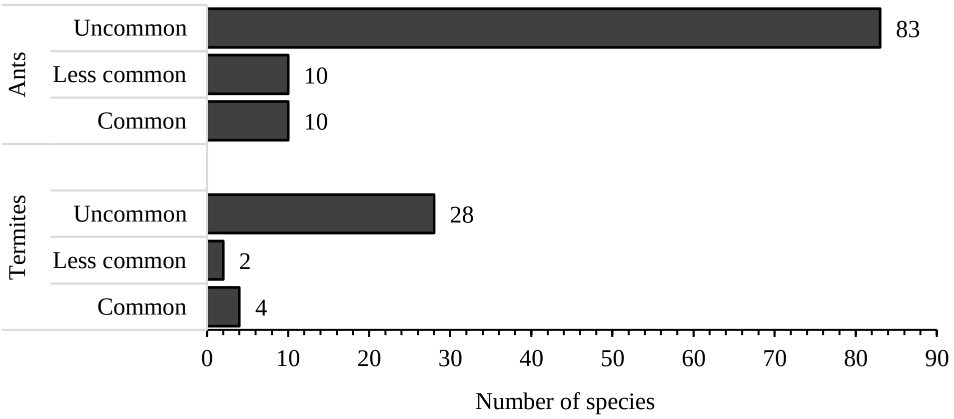

Figure 51: Number of ant and termite prey species commonly, less commonly and uncommonly eaten by white-bellied pangolins.

Table XLIX: Relative importance of ant species eaten preferentially or secondarily by white-bellied pangolins individuals in this study

	Pangolin individuals																
Ant species	WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	**Ar**	**Fo**	RI	Cat
Tapinoma melanocephalum	0.01 (3)	0 (0)	0.09 (4)	0.01 (2)	0 (0)	0.01 (1)	0 (0)	1.11 (392)	0 (0)	0 (0)	0 (0)	0.76 (67)	0 (0)	0.28 (469)	46.15	0.13	**A**
Formicidae sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (18)	23.98 (8432)	0.24 (20)	0.24 (21)	0 (0)	4.09 (360)	0 (0)	5.36 (8851)	38.46	2.06	**C**
Formicidae sp.4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.19 (420)	0 (0)	5.09 (450)	15.02 (290)	0 (0)	28.14 (300)	0.88 (1460)	30.77	0.27	**A**
Anoplolepis carinata	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	52.66 (9019)	0.85 (300)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5.64 (9319)	15.38	0.87	C
Anoplolepis tenella	4.2 (1380)	0.73 (92)	2.41 (113)	0.41 (68)	0 (0)	0 (0)	2.22 (381)	2.03 (714)	0 (0)	64.72 (5727)	2.28 (44)	4.71 (415)	11.91 (127)	5.49 (9061)	76.92	4.22	C
Camponotus brutus	0.01 (2)	0 (0)	0 (0)	0.01 (2)	0.07 (6)	0 (0)	0.74 (126)	0.09 (31)	0.7 (59)	0.31 (27)	0.05 (1)	1.65 (145)	2.72 (29)	0.26 (428)	76.92	0.2	A
Camponotus chapini	8.32 (2734)	12.97 (1633)	0.64 (30)	0.42 (69)	11.45 (971)	0.01 (1)	0.04 (6)	0.21 (75)	0.13 (11)	0 (0)	0 (0)	0.02 (2)	0 (0)	3.35 (5532)	76.92	2.58	C
Camponotus flavomarginatus	1.3 (428)	6.2 (781)	0.43 (20)	0.33 (54)	4.14 (351)	0.3 (26)	0.23 (40)	0.02 (6)	0.1 (8)	0.19 (17)	0.16 (3)	0.01 (1)	0 (0)	1.05 (1735)	92.31	0.97	C
Camponotus maculatus	0.21 (68)	0.81 (102)	0.79 (37)	0.01 (2)	0 (0)	0.09 (8)	0.45 (77)	0 (0)	2.78 (234)	0.14 (12)	0 (0)	0 (0)	0.09 (1)	0.33 (541)	69.23	0.23	A
Polyrachis militaris	0.02 (5)	3.44 (433)	1.13 (53)	0.37 (61)	0.27 (23)	0.02 (2)	0.49 (84)	0.14 (50)	2.84 (239)	0.59 (52)	0 (0)	2.74 (241)	0 (0)	0.75 (1243)	84.62	0.64	C
Crematogaster (*Oxygyne*) sp.1	14.72 (4839)	0 (0)	0.62 (29)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.95 (4868)	15.38	0.45	A
Crematogaster (*Oxygyne*) sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (1)	7.57 (667)	9.85 (105)	0.47 (773)	23.08	0.11	A
Crematogaster acis	0 (0)	29.41 (3702)	26.84 (1260)	0.88 (145)	4.75 (403)	3.93 (341)	3.4 (583)	4.27 (1502)	2.08 (175)	0.46 (41)	17.92 (346)	0 (0)	0.19 (2)	5.15 (8500)	84.62	4.35	C
Crematogaster concava	9.17 (3012)	0 (0)	0 (0)	0.41 (68)	10.75 (912)	24.42 (2120)	1.54 (263)	0.34 (120)	0 (0)	0.07 (6)	0 (0)	0 (0)	0 (0)	3.94 (6501)	53.85	2.12	C
Crematogaster gabonensis	0 (0)	12.23 (1540)	8.95 (420)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.19 (1960)	15.38	0.18	A
Monomorium sp.1	0.01 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.04 (6)	9.6 (3375)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.05 (3384)	23.08	0.47	A
Pheidole albidula	0 (0)	3.97 (500)	0.02 (1)	0.04 (6)	0 (0)	0 (0)	1.79 (306)	0 (0)	8.32 (700)	0 (0)	0 (0)	0 (0)	0 (0)	0.92 (1513)	38.46	0.35	**A**
Pheidole megacephala	10.95 (3600)	4.8 (604)	1.15 (54)	4.22 (697)	4.78 (405)	1.18 (102)	5.73 (981)	9.39 (3300)	0 (0)	0.59 (52)	0 (0)	0 (0)	0 (0)	5.93 (9795)	69.23	4.11	C

Pheidole minima	8.39 (2757)	4.15 (523)	0.96 (45)	0.02 (3)	0 (0)	0.17 (15)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.02 (3344)	46.15	0.93	**C**
Pheidole sp.2	7.3 (2400)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.45 (2400)	7.69	0.11	A

The numbers into parentheses represent the numbers of individuals for each species recorded in pangolin stomachs. Ar= relative abundance; Fo= frequency of occurrence; RI=relative importance of prey; Cat= Category; WBP= white-bellied pangolin, C= Constant or common prey/consumed preferentially; A= Accessory or less common prey/ secondarily consumed.

III.1.4.1.1.6 Termite species eaten by white bellied pangolins

Overall, 39 termite species (27.08% of all prey eaten and 55.0% of potential preys) were recorded in 13 pangolin stomach contents. Five species (3.47% of all preys) were preferentially eaten by white-bellied pangolins, including *Pseudacanthotermes militaris* (RI=17.10; 18,124 individuals) followed by *Nasutitermes arborum* (RI=16.85; 30,144 individuals), *Macrotermes amplus* (RI=2.11; 2,049 individuals), and *Macrotermes bellicosus* (RI=0.57; 3,479 individuals, Fig. 52a). The alate morphospecies *Termittidae* sp. 1 was also preferentially eaten (RI=0.98; 2,620 individuals).

Three species (which is 2.08% of all preys) were secondarily eaten by white-bellied pangolin (0.1<RI≤0.5), including *Sphaerotermes sphaerothorax* (642 individuals), *Ancistrotermes crucifer* (383 individuals), and *Trinervitermes occidentalis* (3,810 individuals). Thirty-one species (20.83% of all preys) including 3 alates morphospecies found in the samples were uncommon (see appendix 6). Figure 52 shows some preferential termite prey species eaten by white-bellied pangolin.

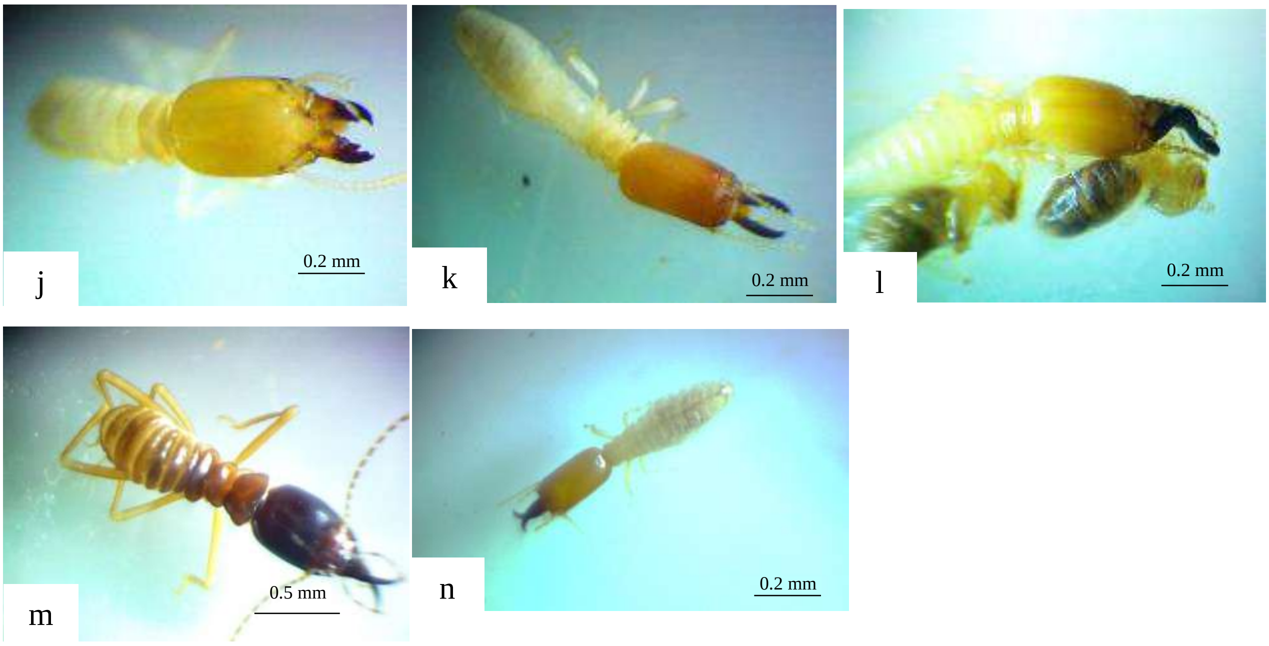

Figure 52: Termite prey species eaten by white-bellied pangolins (a, b, c, d) =Preferential termite prey species eaten (a) *Macrotermes bellicosus* minor soldier, (b) *Pseudacanthotermes militaris* major and minor soldiers, (c) *Nasutitermes arborum* soldier and workers, (d) *Macrotermes amplus* minor soldier, (e, f, g)=secondarily or less common eaten I *Acanthotermes acanthothorax* minor soldier, (f) *Trinervitermes occidentalis* soldier and workers, (g) *Sphaerotermes sphaerothorax* and Accidentally or uncommon prey/rarely eaten (h) *Ancistrotermes crucifer* soldier and workers, (i) *Nasutitermes fulleri*, (j) *Protermes hirticeps*, (k) *Microcerotermes parvus*, (l) *Pericapriterms urgens* soldier and workers, (m) *Macrotermes lilljeborgi*,minor soldier (n) *Microcerotermes silvestrianus.*

Table L presents actual and relative abundance of termite species eaten preferentially or secondarily by white-bellied pangolin individuals in this study.

Table L: Relative importance of termite species eaten preferentially or secondarily by white-bellied pangolin individuals in this study

	Pangolin individuals																
Termite species	WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	Ar	Fo	RI	Cat
Ancistrotermes crucifer	0.06 (21)	0.12 (15)	0.77 (36)	0.35 (58)	0.55 (47)	0 (0)	0.29 (50)	0 (0)	1.85 (156)	0 (0)	0 (0)	0 (0)	0 (0)	0.23 (383)	53.85	0.12	A
Macrotermes bellicosus	0 (0)	0.33 (41)	0 (0)	1.48 (245)	0 (0)	0 (0)	15.31 (2622)	1.39 (490)	0.1 (8)	0.71 (63)	0 (0)	0.11 (10)	0 (0)	2.11 (3479)	53.85	1.13	C
Macrotermes amplus	0 (0)	0 (0)	29.27 (1374)	0 (0)	0.21 (18)	0 (0)	0 (0)	0.57 (200)	0 (0)	2.42 (214)	0 (0)	2.17 (191)	4.88 (52)	1.24 (2049)	46.15	0.57	**C**
Pseudacanthotermes militaris	2.5 (821)	8.6 (1082)	2.34 (110)	3.67 (606)	0.78 (66)	61.51 (5339)	5.26 (901)	5.2 (1829)	57.77 (4859)	8.79 (778)	0 (0)	16.41 (1446)	26.92 (287)	10.97 (18124)	92.31	10.13	C
Nasutitermes arborum	10.04 (3300)	0.6 (75)	2.24 (105)	62.64 (10337)	5.79 (491)	0 (0)	0.04 (6)	31.01 (10901)	0.33 (28)	7.36 (651)	16 (309)	44.63 (3932)	0.84 (9)	18.25 (30144)	92.31	16.85	C
Trinervitermes occidentalis	0 (0)	0 (0)	0 (0)	0 (0)	44.92 (3810)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.31 (3810)	7.69	0.18	A
Sphaerotermes sphaerothorax	1.24 (408)	0 (0)	0 (0)	1.09 (180)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.59 (52)	0 (0)	0 (0)	0.19 (2)	0.39 (642)	30.77	0.12	**A**
Termitidae sp.1	0 (0)	0 (0)	0 (0)	14.61 (2411)	0.51 (43)	0 (0)	0.06 (11)	0.15 (53)	0.89 (75)	0.06 (5)	0.88 (17)	0.06 (5)	0 (0)	1.59 (2620)	61.54	0.98	C

The numbers into parentheses represent the numbers of individuals for each species recorded in pangolin stomachs. Ar= relative abundance; Fo= frequency of occurrence; RI=relative importance of prey; Cat= Category; WBP= white-bellied pangolin, C= Constant or common prey/consumed preferentially; A= Accessory or less common prey/ secondarily consumed preys.

III.1.4.1.2 Termite and ant prey's species

A total of 144 insect species and morphospecies were identified in the stomachs of 13 white-bellied pangolins comprising 3 families, 12 subfamilies and 42 genera, including 39 termite species and 105 ant species. Four termite and four ant morphospecies preys were precluded from species richness estimation.

III.1.4.1.2.1 Termite prey species

III.1.4.1.2.1.1 Termite prey species eaten by pangolin

Overall, the percentage of termite species eaten (that is meal in one individual stomach content) has varied significantly (χ^2=89.88, df=12, p<0.001) between pangolin individuals during the same meal. The number of termite prey species eaten ranged between one (2.87% of all termite preys eaten) to 13 (37.14%) prey species eaten per pangolin individual. The percentage of prey species eaten by pangolin individuals WBP02, WBP03, and WBP04 (respectively 12, 13, and 12 species) were higher and lower among WBP06 meal (with a single species eaten).

III.1.4.1.2.1.2 Ant prey species in pangolin stomachs

Overall, the percentages of ant species eaten had varied significantly (χ^2=76.88, df=12, p<0.0001) between pangolin individual meals. Preys eaten by examined pangolin individuals ranged between seven (6.93% of all ant prey species) to 31 (30.69%) ant species eaten per pangolin individual. Ant species percentages were higher in the meal of individuals WBP07 and WBP04 (31 species) and lower in WBP11 meal with seven species (Fig. 53).

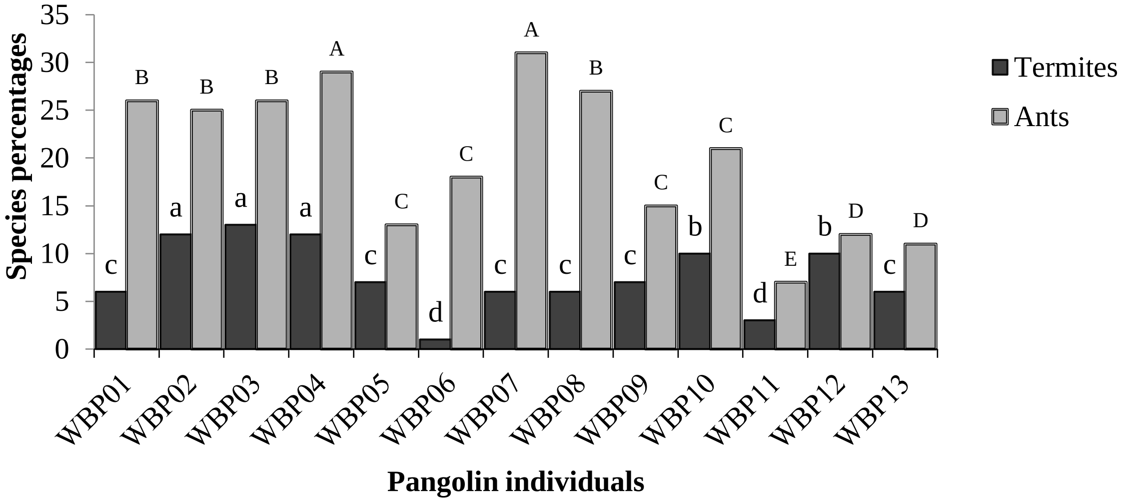

Figure 53: Percentages of ant and termite species in 13 pangolin individual stomachs examined. Different low case and capital letters on the histogram indicate significant differences following pairwise comparisons of species percentage of ant and termite prey species between different pangolin individual meals.

III.1.4.1.3. Average abundance of preys

III.1.4.1.3.1 Average abundance of termite preys

The means abundance of termites consumed were significantly different (H=12.12; df=12; p=0.002; Table LI) between pangolin individual meals. The WBP04 has the highest mean abundance (375.11±276.96) of termites eaten, followed by WBP08 (370.82±289.2). Pangolin individuals WBP13 and WBP11 showed the lowest termite abundance means (11.34±7.78) and (24.79±14.71), respectively.

Table LI: Means abundance of termite species eaten by 13 white-bellied pangolin individuals.

Pangolin Individual Numerous	**Means**
WBP01	4893 (128.76±89.29)^{b}
WBP02	2091 (55.03±30.99)^{c}
WBP03	1656 (43.58±36.18)^{c}
WBP04	14254 (375.11±276.96)^{a}
WBP05	4478 (117.84±100.63)^{b}
WBP06	5339 (140.5±140.5)^{b}
WBP07	4101 (107.92±72.62)^{b}
WBP08	14091 (370.82±289.2)^{a}
WBP09	5247 (138.08±127.69)^{b}
WBP10	1943 (51.13±26.69)^{c}
WBP11	942 (24.79±14.71)^{d}
WBP12	6016 (158.32±108.94)^{b}
WBP13	431 (11.34±7.78)^{d}
Kruskal-Wallis test	**H=12.12**
p-value	**p=0.002**

WBP= white-bellied pangolin. The numbers in brackets indicate the mean values of termite abundances and their Standard errors. (Mean ± standard error (Standard Error)) and the numbers before brackets are absolute abundances. Kruskal-Wallis test was corrected with Bonferroni procedure, test p-value is significant if p<0.003 between pangolin individuals. The different letters at the mean values indicate significant differences following pairwise comparisons of different means abundance between pangolins individuals.

III.1.4.1.3.2 Average abundance of ant preys

The means abundance of ants consumed by white-bellied pangolins had varied significantly (H=21.54; df=12; p<0.0001) between pangolin individuals. WBP01 had the highest abundance means (266.24±84.33), followed by WBP08 (200.63±92.45). WBP13 and WBP11 had the lowest means of ant abundance (6.03±3.25) and (9.42±4.92), respectively (see Table LII).

Table LII: Mean abundance of ant species recorded in 13 white-bellied pangolin meals.

Pangolin individual Numerous	**Means**
WBP01	27,955 (266.24±84.33)^{a}
WBP02	10,497 (99.97±42.22)^{b}
WBP03	3,038 (28.93±13.78)^{c}
WBP04	2,248 (21.41±8.16)^{d}
WBP05	4,003 (38.12±14.64)^{c}
WBP06	3,341 (31.82±20.64)
WBP07	13,022 (124.02±86.46)^{b}
WBP08	21,066 (200.63±92.45)^{a}
WBP09	3,164 (30.13±14.02)^{c}
WBP10	6,905 (65.76±54.68)^{bc}
WBP11	989(9.42±4.92)^{e}
WBP12	2,790 (26.57±10.56)^{d}
WBP13	633 (6.03±3.25)^{e}
Kruskal-Wallis test	**H=21.54**
p-value	**P<0.0001**

WBP=white-bellied pangolin. The numbers in brackets indicate the mean values of termite abundances and their Standard errors. (Mean ± standard error (Standard Error)) and the numbers before brackets are absolute abundances. Kruskal-Wallis test was corrected with Bonferroni procedure, test p-value is significant if p<0.003. The numbers in brackets indicate the mean values of ant abundances and their standard errors. The different letters at the mean values indicate significant differences following pairwise comparisons of different abundance means between pangolins individuals.

III.1.4.1.3.2.1 Seasonal variation of white-bellied pangolin diet

The mean abundance of termite species eaten by four individual pangolins during the dry season was higher (373.52±152.45) than in the rainy season (282.79±163.9). There was no significant variation (U=1.4; p=0.1) in the mean abundance of termites eaten between the two groups of four pangolins individuals. A different trend was observed for mean abundance of ants consumed which was significantly higher (H=4.43; p<0.00001) in the dry season (see Table LIII).

Table LIII: Mean abundance of termite and ant species in 4 white-bellied pangolin stomach contents per season

Preys	**Seasons**	**Means**
Sample size	4	-
Termites	Dry	12,326 (373.52±152.45)^a
	Rainy	9,332 (282.79±163.9)^a
	Mann-Whitney U	U=1.44
	P-value	p=0.15
Ants	Rainy	30,560 (418.63±154.04)^a
	Dry	11,317 (155.03±89.21)^b
	Mann-Whitney U	U=4.43
	P-value	p<0.0001

The numbers in brackets indicate the mean values of termite abundances and their Standard errors [Mean ± standard error (Standard Error)] and the numbers before brackets are absolute abundances. The different letters at the mean values indicate significant differences after comparisons of different abundance means.

III.1.4.1.3.2.2 Variation of preferential preys eaten by white-bellied pangolin individuals

Genera

The Correspondence Analysis (CA) of white-bellied pangolin individuals prey compositions has grouped examined WBP in three clusters according to their main preys (Fig. 54a). The first cluster is formed by WBP04, WBP12, and WBP08. This group has preponderance of prey species from the genera *Nasutitermes*, *Monomorium*, *Termitidae gen.*1, and *Formicidae gen*.2 (Fig. 54a). The second group formed by WBP07 and WBP10 has fed mostly on prey from the genera *Anoplolepis* and *Macrotermes*. The third group formed by WBP02, WBP06, WBP09, WBP05, WBP01, WBP09 and WBP11 had fed predominantly on the genera *Camponotus*, *Odontotermes*, *Polyrachis*, *Formicidae gen* 1, *Pseudacathotermes*, *Pheidole*, and *Crematogaster.*

Species

Although the *CA* of the 13 examined pangolin individuals has shown three distinct groups at the genera level (Fig. 54b), most of the examined WBP have eaten almost the same prey species, including *Pheidole megacephala*, *Anoplolepis tenella*, *Macrotermes amplus*, *Crematogaster acis*, *Campnotus flavomarginatus*, *Pheidole mintita* and others (Fig. 54b). WBP10 fed on *Anoploepis tenella* and *Pheidole minima* more than the other pangolins. *Macrotermes bellicosus*, *Anoplolepis carinata*, and *Nasutitermes fulleri* were common preys recorded in the meals of WBP07, the same for *Tetramorium* sp. in WBP04 meal. The strength of association between the main prey species recorded and each examined pangolin individual is shown in Fig. 54b. The lower the distance values between the eaten prey item (blue circle) and individuals (red triangle), the more frequently the prey was eaten by the pangolin individual.

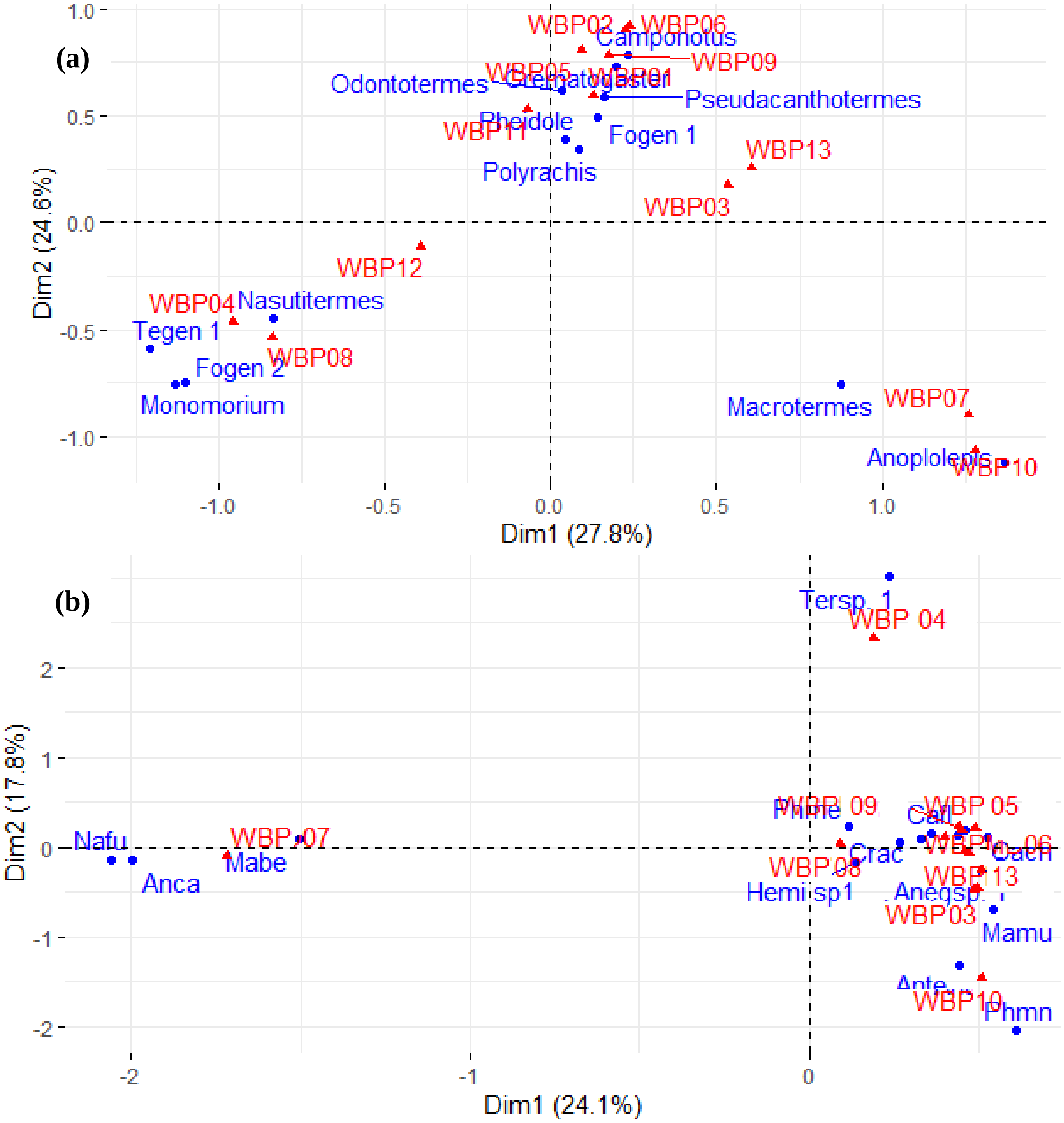

Figure 54: Correspondence Analysis of the distribution of ant and termite prey preferentially eaten by white-bellied pangolin individuals. (a) at genera and (b) species levels. Dimensions (Dim1 and Dim2) explain 52.2% and 41.9% of the total variance on Fig a and b respectively. The blue circles represent ant or termite

prey and the red triangles represent each pangolin individual. Some prey species points and pangolin individuals are unlabeled due to overlapping with other points. WBP=white-bellied pangolin. The codes of species name are made by the two first letters of the name of genus followed by the two letters of the name of species (e.g., Cabr=*Camponotus brutus*) or the two letters of the genus name followed by the symbol sp. (e.g., Alsp.1=*Allodontotermes* sp.1) Or the two letters of the genus name followed by the two letters of the subgenus name into brackets (e.g. *Ca* (*Ta*) sp. =*Camponotus* (*Tanaemyrmex*) sp.).

III.1.4.1.3.2.3 Variation of all preys eaten by white-bellied pangolin individuals

III.1.4.1.3.2.3.1 Ants

Based on their last meal compositions, the examined pangolin individual meals revealed three distinct groups. The first formed by WPB08, WBP11, WBP12, WBP04, WBP10, and WBP13 shared 17 species, including *Lepisiota occulata*, *Camponutus bucholzi*, *Pheidole megacephala*, and other species (Fig. 55a). The second group formed by WPB01, WBP02, WBP03, WBP05, and WBP06 shared 18 species. Both pangolin groups 1 and 2 have shared in their meals *Crematogaster acis* and *Polyrachis militaris*. Individual WBP09 meal has slightly differed from other individuals with *Axinidris* sp.2, *Camponotus maculatus*, *Dorylus* sp.2, and *Camponotus* (*Paramyrmablys*) sp. and ant eggs morphotypes 2. The most different meal was from WBP07 with four distinct prey species (Fig. 55a). Nine ant species were not specific to any pangolin individuals (Fig. 55a), including *Technomyrmex* sp.3, *Dorylus* sp.1, *Camponotus brutus*, *Technomyrmex* sp.2**,** *Hypoponera intermedia*, *Hypoponera cognata*, *Camponotus pompeuis*, *Polyrachis* sp.1, and *Pheidole albidula*.

III.1.4.1.3.2.3.2 Termites

A similar trend was observed with termite species in pangolin individuals' meals. The examined pangolins revealed four principal groups of individuals (Fig. 55b). The first formed by WBP08, WBP11, WBP01, WBP04, WBP05, and WBP12 had shared 15 termite prey species in their meals, including *Trinervitermes occidentalis, Acanthotermes acanthothorax*, *Allodontotermes* sp., *Odontotermes* sp., and *Isognathotermes* sp.. The second group formed by WBP10, WBP13, WBP06, WBP02 and WBP09 shared eight prey species (Fig. 55b). The WBP07's individual meal has differed especially with *Nasutitermes fulleri, Macrotemes bellicocsus*, and *Macrotermes* sp.. The individula WBP03 formed a singleton group with a meal, including *Microcerotermes silvestrianus, Macrotermes mueleri, Odontotermes fulleri, Ophiotermes ugandensis, Microtermes osborni*, and *Isognathotermes zenkeri* (synomym *Cubitermes kemri*).

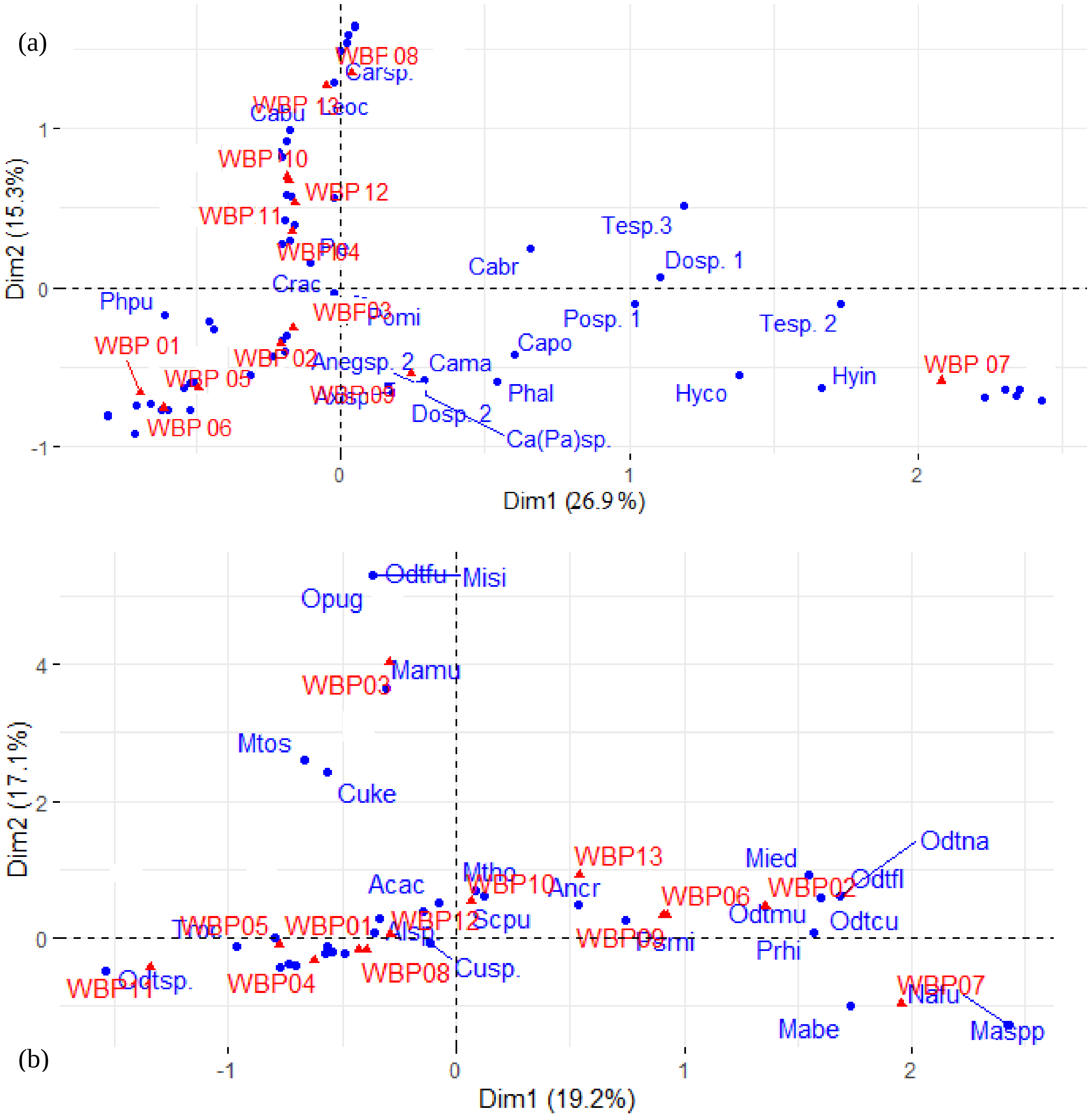

Figure 55: Correspondence Analysis showing the affinity of all (a) ant and (b) termite prey item eaten according to white-bellied pangolin individuals. Dimensions (Dim1 and Dim2) on Fig. a and b explain 42.2% and 36.3% of the total variances respectively. The blue circles represent ant prey species (a) or termite prey species (b) and red triangles represent each pangolin individual. Some species points (circles) are unlabeled due to overlapping with other points. WBP=white-bellied pangolin. The abbreviations in blue are codes name of species preys.

III.1.4.1.4 Comparison of white-bellied pangolin individuals’ meals

III.1.4.1.4.1 Prey species shared between white-bellied pangolin individuals

III.1.4.1.4.1.1 Ants shared prey species

All pangolin individuals examined had shared at least two ant prey species in their meals. Some individuals have shared up to 15 ant species (14.29% of all ant prey species consumed). They included WBP02 with WBP03, and WBP04 and WBP07 (see Table LIV).

III.1.4.1.4.1.1 Termites shared prey species

Except the pair of individual WBP11 and WBP06’s meals which have no termite prey species in common, all other pangolin individuals had shared at least one termite prey species in their meals (see Table LVI). Some pangolin individual meals such as WBP11 and WBP12 have shared up to 12 termite prey species (which is 21.05% of all prey species consumed). Table LIV and Table LVI summarize respectively the relative proportions of ant and termite prey species shared between pangolins individual meals.

III.1.4.1.4.2 Similarity of white-bellied pangolin meals’ composition

III.1.4.1.4.2.1 Similarity of ant species in the composition of pangolin meals

Overall, the white-bellied pangolin individual meals were mostly dissimilar in terms of their composition of ant prey species. The Brays-Curtis dissimilarity index ranging from Cn= 0.002 to Cn=0.449 has shown a low similarity of pangolin individual meals in terms of ant composition (see Table LV). The most similar meals were from WBP11 and WBP13 which shared 11 prey species (this is 10.48 % of all ant species eaten by all pangolins). The least similar meals were observed between WBP13 and WP06, and WBP12 and WBP06 (Cn= 0.002.

III.1.4.1.4.2.2 Similarity of termite species in the composition of pangolin meals

Based on the Brays-Curtis dissimilarity index, pangolin pair WBP06 and WBP09 had the most similar meals (Cn=0.918) followed WBP01 and WBP12 (Cn=0.756), WBP04 and WBP08 (Cn=0.793), then WBP08 and WBP12 (Cn=0.557; Table LVII). The least similar pangolin meals are those from WBP06 and WBP11 (Cn=0; Table LVII) which has not species in common. These trends are confirmed by the dendrograms, however the node between WBP06 and WBP09 is not significant (AU P value=88%; Fig.56). The bold in the table indicate the higher Brays-Curtis similarity index values between the pairs of pangolin individual meals.

Table LIV: Number of ant species (relative proportions of ant prey species) shared between pangolin examined individuals and similarity of meals. The numbers in parenthesis are the relative proportions of ant prey species shared between pangolin examined individuals.

WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	
1	11 (10.48)	14 (13.33)	11 (10.48)	8 (7.62)	9 (8.57)	13 (12.38)	9 (8.57)	7 (6.67)	9 (8.57)	4 (3.81)	8 (7.62)	5 (4.76)	WBP01
	1	15 (14.29)	13 (12.38)	7 (6.67)	7 (6.67)	13 (12.38)	9 (8.57)	11 (10.48)	10 (9.52)	4 (3.81)	7 (6.67)	6 (5.71)	WBP02
		1	11 (10.48)	6 (5.71)	9 (8.57)	12 (11.43)	8 (7.62)	7 (6.67)	8 (7.62)	3 (2.86)	6 (5.71)	4 (3.81)	WBP03
			1	9 (8.57)	10 (9.52)	15 (14.29)	14 (13.33)	10 (9.52)	10 (9.52)	6 (5.71)	8 (7.62)	6 (5.71)	WBP04
				1	6 (5.71)	9 (8.57)	7 (6.67)	7 (6.67)	8 (7.62)	4 (3.81)	5 (4.76)	3 (2.86)	WBP05
					1	8 (7.62)	9 (8.57)	5 (4.76)	8 (7.62)	2 (1.9)	4 (3.81)	2 (1.9)	WBP06
						1	14 (13.33)	10 (9.52)	12 (11.43)	5 (4.76)	7 (6.67)	6 (5.71)	WBP07
							1	9 (8.57)	12 (11.43)	6 (5.71)	9 (8.57)	7 (6.67)	WBP08
								1	10 (9.52)	4 (3.81)	7 (6.67)	6 (5.71)	WBP09
									1	9 (8.57)	**11 (10.48)**	**11 (10.48)**	WBP10
										1	8 (7.62)	9 (8.57)	WBP11
											1	9 (8.57)	WBP12
												1	WBP13

Table LV : Bray-Curtis' dissimilarity indices comparing composition of ant prey species in pairs of white-bellied pangolin individual meals

WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	
1	0.177	0.033	0.068	0.177	0.153	0.087	0.172	0.032	0.103	0.021	0.071	0.011	WBP01
	1	0.33	0.17	0.303	0.072	0.156	0.15	0.16	0.037	0.075	0.059	0.023	WBP02
		1	0.143	0.153	0.146	0.116	0.126	0.093	0.063	0.195	0.06	0.064	WBP03
			1	0.267	0.16	0.149	0.126	0.112	0.07	0.169	0.086	0.074	WBP04
				1	0.377	0.136	0.083	0.111	0.06	0.208	0.059	0.016	WBP05
					1	0.091	0.055	0.06	0.03	0.159	0.002	0.002	WBP06
						1	0.16	0.092	0.067	0.061	0.084	0.025	WBP07
							1	0.026	0.099	0.065	0.083	0.043	WBP08
								1	0.101	0.21	0.243	0.036	WBP09
									1	0.172	0.185	0.137	WBP10
										1	0.186	**0.461**	WBP11
											1	0.187	WBP12
												1	WBP13

Table LVI: Number of species (relative proportions of termite prey species) shared between examined pangolin individuals and similarity of meals. The numbers in parenthesis are the relative proportions of ant prey species shared between pangolin examined individuals.

WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	
1	4 (10.53)	4 (10.53)	5 (13.16)	4 (10.53)	1 (2.63)	3 (7.89)	2 (5.26)	3 (7.89)	3 (7.89)	1 (2.63)	**2 (5.26)**	3 (7.89)	WBP01
	1	5 (13.16)	4 (10.53)	3 (7.89)	1 (2.63)	5 (13.16)	3 (7.89)	6 (15.45)	3 (7.89)	1 (2.63)	4 (10.53)	2 (5.26)	WBP02
		1	5 (13.16)	6 (15.79)	1 (2.63)	3 (7.89)	3 (7.89)	4 (10.53)	4 (10.53)	1 (2.63)	5 (13.16)	4 (10.53)	WBP03
			1	5 (13.16)	1 (2.63)	6 (15.79)	**4 (10.53)**	5 (13.16)	6 (15.79)	2 (5.26)	4 (10.53)	3 (7.89)	WBP04
				1	1 (2.63)	4 (10.53)	4 (10.53)	4 (10.53)	4 (10.53)	2 (5.26)	4 (10.53)	3 (7.89)	WBP05
					1	1 (2.63)	1 (2.63)	**1 (2.63)**	1 (2.63)	0 (0)	1 (2.63)	1 (2.63)	WBP06
						1	4 (10.53)	6 (15.79)	4 (10.53)	2 (5.26)	4 (10.53)	2 (5.26)	WBP07
							1	4 (10.53)	6 (15.79)	3 (7.89)	**6 (15.79)**	3 (7.89)	WBP08
								1	5 (13.16)	2 (5.26)	**5 (13.16)**	3 (7.89)	WBP09
									1	3 (7.89)	8 (21.05)	5 (13.16)	WBP10
										1	4 (10.53)	1 (2.63)	WBP11
											1	5 (13.16)	WBP12
												1	WBP13

Table LVI: Bray-Curtis' dissimilarity indices comparing similarity of composition of termite prey species in pairs of white-bellied pangolin individual meals

WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	
1	0.262	0.075	0.436	0.124	0.16	0.189	0.434	0.172	0.433	0.106	**0.756**	0.112	WBP01
	1	0.108	0.09	0.047	0.291	0.319	0.148	0.334	0.443	0.049	0.288	0.235	WBP02
		1	0.033	0.075	0.031	0.054	0.053	0.052	0.242	0.081	0.108	0.171	WBP03
			1	0.069	0.062	0.1	**0.793**	0.079	0.17	0.043	0.449	0.041	WBP04
				1	0.013	0.03	0.067	0.038	0.181	0.12	0.111	0.038	WBP05
					1	0.191	0.188	**0.918**	0.214	0.00	0.255	0.099	WBP06
						1	0.155	0.214	0.282	0.007	0.182	0.129	WBP07
							1	0.198	0.214	0.046	**0.557**	0.048	WBP08
								1	0.228	0.015	0.264	0.105	WBP09
									1	0.311	0.433	0.319	WBP10
										1	0.117	0.013	WBP11
											1	0.133	WBP12
												1	WBP13

III.1.4.1.4.2 Similarity of white-bellied pangolin individual meals

Similarity of termite and ant prey specific composition

Based on termite communities that constitute their last meals, the dendrogram from examined pangolin individuals has formed 10 nodes and two clusters with highly significant nodes (100% AU p-value; Fig. 56). The first cluster is formed by WBP04 and WBP08 suggesting that the specific composition of the meals of these pangolin individuals are strongly similar and significantly different (100% AU p-value) to the nearest group formed by WBP06 and WBP09 in the second cluster which also included WBP12, WBP05, WBP07, WBP03, WBP11, WBP 13, WBP10 and WBP02. Whitin this group 2 sub-clusters having highly similar meals are formed including, WBP06 and WBP09, followed by WBP02 and WBP10 with non-significant nodes. While WBP11 and WBP13 had more similar meals composition (97% AU p-value node) than other individuals.

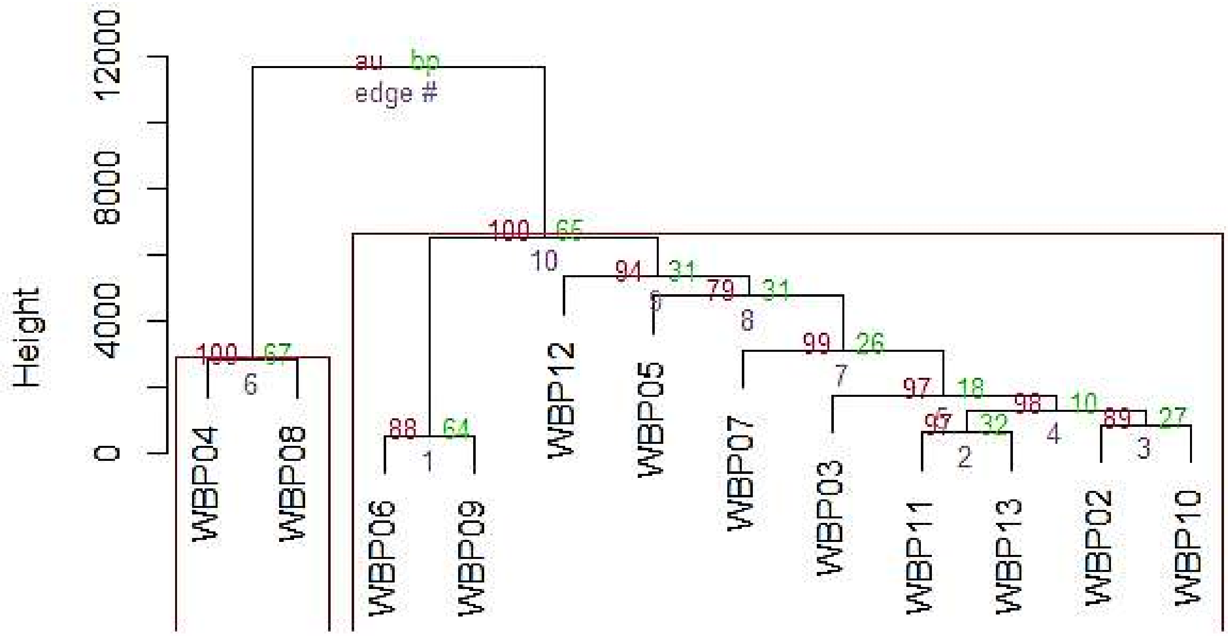

Figure 56: Dendrogram showing the similarity of the stomach content termite-specific composition of the examined pangolin individuals. The results display at each node of the dendrogram as red, gray, and green numbers (the gray numbers are the node number). The green number is the Bootstrap Probability 100 (BP). The red number is the Approximately Unbiased p-value 100 (highly significant if AU ≥ p-value **95**).

For ants dendrogram, 10 nodes and one cluster are formed precluding three pangolin individuals with a significantly robust node (95% AU p-value; Fig. 57). This suggests that the ant prey communities in each examined pangolin individual belonging to the cluster are more significantly (97% AU p-value; Fig. 57) similar to each other than to the individuals on external branches. In other words, these pangolin individuals included in the cluster have preyed on a more similar prey species composition than other individuals. Individual WBP10, WBP07, and WBP08 had formed a significant node (95% AU p-value) suggesting a strong different in their meal compositions. Among the three individuals, the species composition of WBP07 and WBP08 meals were more similar together than that of WBP10. Within the large cluster WBP02 meal has significantly differed from other meals (97% AU p-Value), similarly WBP05 and WBP06 meals were strongly different (98% AU p-value). These three individual meals were strongly different (100% AU p-value) to WBP03, WBP09 which meals were highly (96% AU p-value) from that of WBP12, WBP04, WBP11 and WBP13.

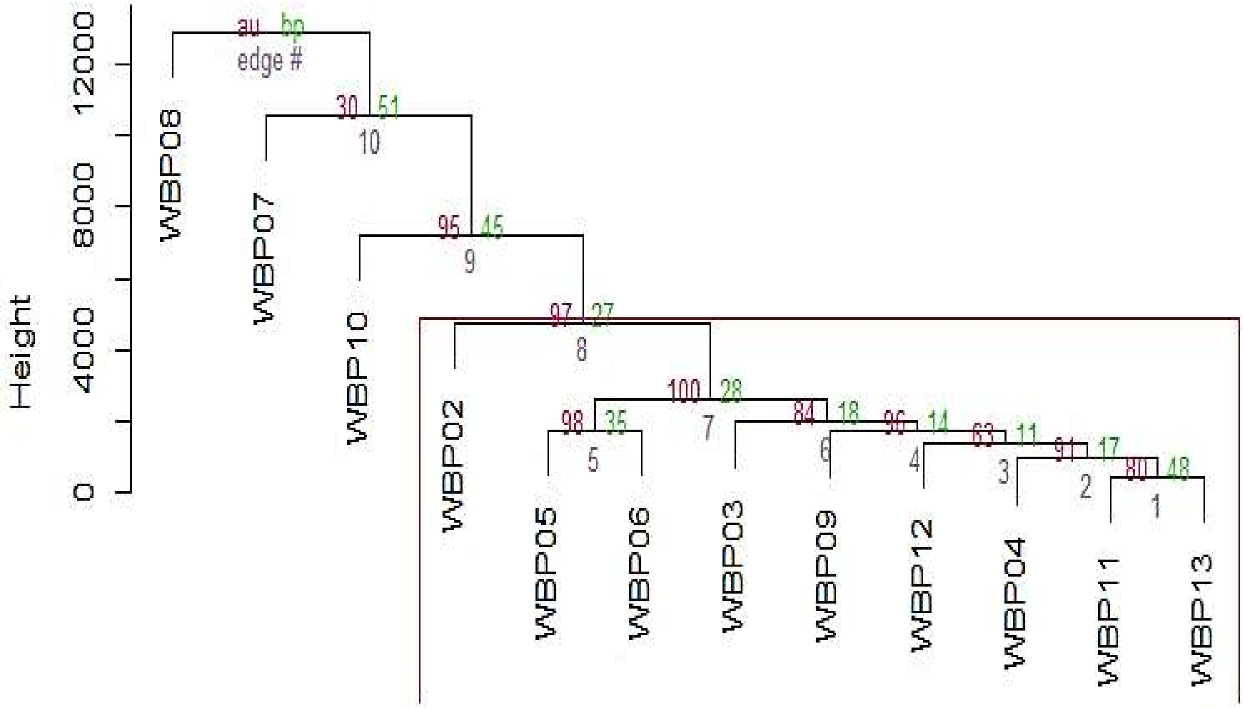

Figure 57: Dendrogram showing the similarity of the stomach content's ant-specific composition of the examined pangolin individuals. The results display at each node of the dendrogram as red, gray, and green numbers (the gray numbers are just the node number). The green number is the Bootstrap Probability 100 (BP) and has the most straightforward interpretation. The red number is the Approximately Unbiased p-value 100 (highly significant if AU ≥ p-value **95**) and is a corrected version of BP to limit bias. WBP=white-bellied pangolin

Similarity of pangolin prey and insect communities in habitat types

A unique cluster formed between WBP13, WBP12, WBP11, WBP05, WBP03, WBP06, WBP02, WBP04 and almost all habitats suggests that the specific composition of these meals was strongly similar to the prey communities in all sampled habitats except MDNPNPF. The cluster node was significantly different (100% AU p-value) to the nearest group formed by WBP10 and WBP02 which meals were similar to MDNPSF. WBP05 and WBP06 meals composition were significantly (98% AU p-value) similar to MDNPF insect community. A third group formed by WBP07 WBP01 and WBP08 was not significantly different from the previous and were strongly dissimilar to ant habitat communities. The dendrogram of Fig. 58 shows the comparison of the white-bellied pangolin stomach content ant communities with the ant communities from each habitat of MDNP and DDNP

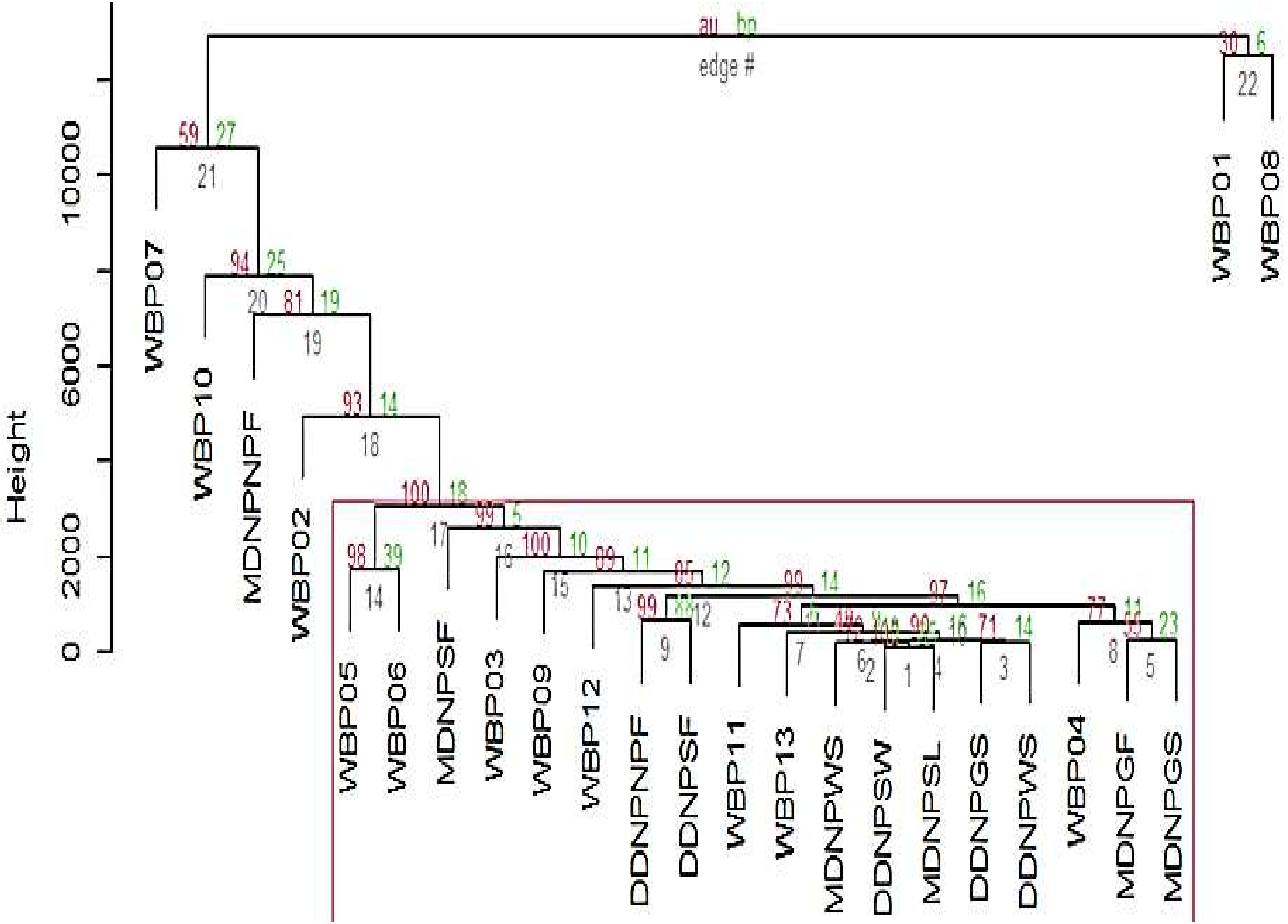

Figure 58: Dendrogram showing the similarity of the stomach content specific composition of the examined pangolin individuals and the habitat insect communities. WBP=white-bellied pangolin. Habitat and park codes are DDNPF= Deng Deng Near primary forest, DDSF= Deng Deng Secondary Forest, DDGS= Deng Deng grassland savanna, DDWS= Deng Deng Woodland savanna, DDGF= Deng Deng Gallery Forest, MDNPF= Mpem et Djim Near primary forest, MDSF= Mpem et Djim Secondary Forest, MDGS= Mpem et Djim grassland savanna, MDWS= Mpem et Djim Woodland savanna, MDGF= Mpem et Djim Gallery forest.

III.1.4.2 Giant pangolin diet composition

III.1.4.2.1 Giant pangolin scat composition

The giant pangolin fecal sample weighed ca 120 grams in dry matter weight. It contained ant and termite body parts (Fig. 59), including (termite and ants heads, ant legs, ant abdomen, ant thorax [27.79%]), ant eggshells (15%), clay (termite mounds) (28.30%), sands (22.56%), plant matter (<1%), stones (<1%), and snail shell (<1%). Other invertebrates recorded include coleoptera (< 1%) and Orthoptera (*Pygomorpha vignudii*) (< 1%).

Figure 59: Giant pangolin dung content: a) Thorax of the ant species; b) mixed fragment of legs of ant species; c) head of different termite species; d) abdomen of ant termite species; e) mixed eggs of ant species.

III.1.4.2.2 Ant species eaten by giant pangolin

The fecal sample had 3,127 ants (88% of insects recorded), belonging to eight ant species. Large and medium-sized ant species were common, such as *Polyrachis militaris* Fabricius, 1781 (2,171 individuals, 61%; Table LVIII) and the larger *Ca. brutus* (538 individuals, 15%). *Tetramorium aculeatum* and *Palthothyreus tarsatus* (Fabricius, 1798) were less abundant. The juvenile giant pangolin stomach content yielded 1,027 ants (71% of insects recorded; Table LVIII) comprising nine species. Large ant species predominated, mostly *Camponotus brutus* Forel 1886 (515 individuals, 35%; Table LVIII), and *Palthothyreus tarsatus* (240 individuals, 17%). Small and medium-sized ant species including *Pheidole* spp. and *Polyrachis militaris* and *Cataulacus weissi* were less abundant. In both, relatively large ant species were most common in the two pangolin's diet as sampled here, namely *Ca. brutus* and *Pa. tarsatus.*

Table LVII: Relative abundance (Ar) of ants between the stomach content and scat of two different individuals of giant pangolin.

Subfamilies	Ant species	GP-Scat (Adult)	GP-Stomach (Juvenile)
Formininae	*Camponotus brutus*	**15 (538)**	**35 (515)**
	Camponotus flavomaginatus (Mayr)	3 (120)	10 (147)
	Camponotus maculatus	-	2 (22)
	Polyrachis laboriosa (F. Smith)	-	2 (27)
	Polyrachis militaris	61 (2171)	1 (8)
	Cataulacus weissi Santschi	4 (150)	-
	Odontomachus tryglotydes Santschi	2 (66)	1 (2)
Ponerinae	*Palthothyreus tarsatus*	1 (7)	17 (240)
Myrmicinae	*Tetramorium acculeatum* (Mayr)	1 (4)	-
	Pheidole sp.1	-	1 (2)
	Pheidole sp.2	2 (71)	4 (63)
	Total	**88 (3127)**	**71 (1026)**

GP= Giant Pangolin. The number of materials examined is one stomach and one scat examined. Dashed cells are where information was not provided. The numbers in parenthesis are absolute abundances.

III.1.4.2.3 Termite species eaten by giant pangolin

Termite preys were less than 30% of the total invertebrates recorded in both the scat and the stomach content. The stomach content yielded 423 termites (29% of insects recorded comprising six termite species (Table LIX). The scat had 439 termites (12% of insects recorded) comprising four species. *Pseudacanthotermes militaris* Hagen 1858 was the most abundant termite species in both pangolins' diet composition (313 [22%] of invertebrates recorded in stomach content and 312 [9%] of invertebrates recorded in scat) followed by *Macrotermes bellicosus* (Smeathman 1781) (89 individuals [6%] in the stomach contents and 74 individuals [2%] in the scat; Table LIX). Both termite species are the largest species sampled in the scat, stomach contents, and from habitats in the protected area. The most abundant termite species fed upon by both giant pangolins. *Ps. militaris*, was sampled most in savanna habitats. *Isognathotermes* sp., *Macrotermes* sp., *Termitidae* sp., *Macrotermes lilljeborgi* and *Ancistrotermes crucifer* were less abundant.

Table LVIII: Relative abundance of termites between the stomach content and scat of two different individuals of giant pangolin.

Subfamilies	Termite species	GP-Scat (Adult)	GP-Stomach (Juvenile)
Cubitermitiae	*Isognathotermes* sp.	-	1 (13)
Macrotermitinae	*Macrotermes bellicosus*	2 (74)	6 (89)
	Ancistrotermes crucifer	-	1(6)
	Macrotermes lilljeborgi	1 (7)	0
	Pseudacanthotermes militaris	9 (312)	22 (313)
	Macrotermes sp.	1 (46)	1 (2)
	Termitidae sp.	-	1 (2)
	Total	**12 (439)**	**29 (425)**

GP= Giant Pangolin; The number of materials examined is one stomach and one scat examined. Dashed cells are where information was not provided. The numbers in parenthesis are absolute abundances.

The comparison of giant pangolin stomach content and scat samples suggests that both pangolin individuals had fed on similar species (six common species representing more than 55% of their diets). Despite their similar composition of species; the stomach content did not closely match that found in the scat sample in terms of relative abundance. *Polyrachis militaris* represented 61% of ants recorded in the pangolin scat compared to 0.5 % in the pangolin stomach contents, where *Camponotus brutus* dominated (35%) the other prey species. This may simply reflect the ant species each individual pangolin most recently fed on.

III.1.4.2.5 Comparison of prey species with the sampled insect community

The giant pangolin stomach and scat content ant communities were compared with the ant communities from each habitat of MDNP where the samples were collected. The primary ant prey *Polyrachis militaris* was primarily collected in grassland savanna (GS) and woodland savanna (WS), while *Camponotus brutus* was most abundant in the near-primary forest (NPF) and secondary forest (SF).

III.1.4.3 Pangolin's prey selectivity

III.1.4.3.1 white-bellied pangolin prey selectivity

III.1.4.3.1.1 Termite prey selection

Trinervitermes occidentalis, Pseudacanthotermes militaris, Odontotermes stanleyvillensis, Odontotermes munkibunginis, Nasutitermes arborum, Macrotermes amplus, Macrotermes bellucosus, Allodontotermes sp.1, and *Acanthotermes acanthothorax* appear to have been positively selected (Fig. 60) among the sampled prey available. Among these preys, *Ma. bellicosus* likelihood of selection is twice higher than all the other prey (note that it is not for all pangolin examined). None of the species have been used proportionally to their frequency of collection in general surveys, while, three species from the general collections were not ingested, including *Microtermes osborni, Microcerotermes silvestrianus*, and *Isognathotermes zenkeri*. Figure 60 shows forage ratios and selection probability (Bi; represented by the asterisks) of each termite prey showing white-bellied pangolin preference.

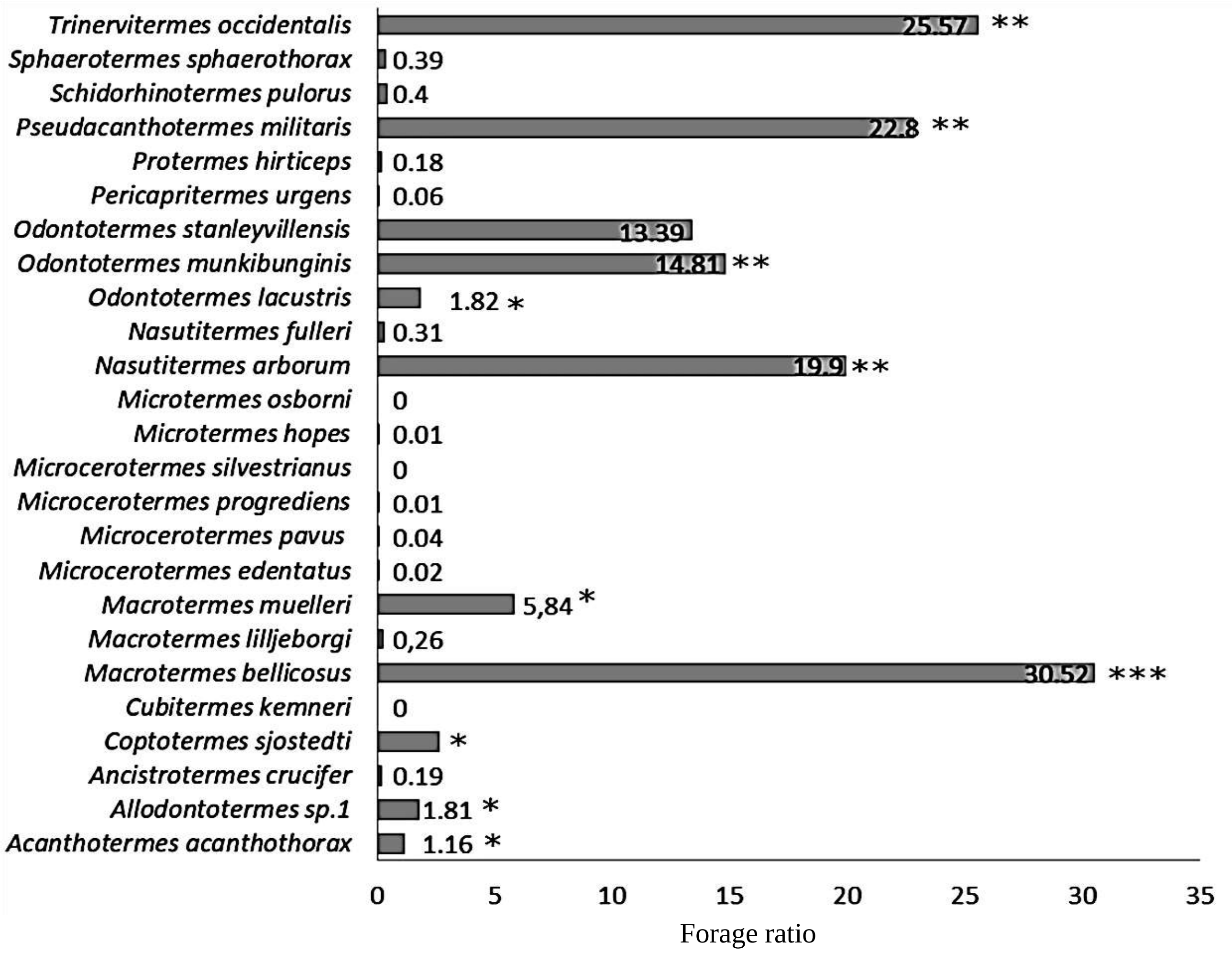

Figure 60: Forage ratios (Wi) and selection probability (Bi; represented by the asterisks) of each termite prey showing white-bellied pangolin preference. Wi values are represented by the bars and Bi with asterisks *** denote the highest probability of prey selection, ** higher probability of prey to be selected, and * lower probability of prey to be selected.

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III.1.4.3.1.2 Ant prey selection

Crematogaster acis, *Pheidole minima*, *Pheidole megacephala*, *Pheidole* sp.1, *Pheidole* sp.2, *Pheidole* sp.3, *Pheidole albidula*, *Crematogaster* (*Oxygyne*) sp.2, *Crematogaster* (*Oxygyne*) sp.1, *Crematogaster* sp.2, *Crematogaster* (*Decacrema*) sp.1, *Camponotus* sp.2, *Camponotus* sp.1 *Camponotus maculatus*, *Camponotus brutus*, *Camponotus pompeius Camponotus flavomarginatus*, *Camponotus chrysurus*, *Anoploepis tenella*, *Anoplolepis carinata*, *Polyrachis decemdentata*, *Leptogenus vindicis*, *Hypoponera cognata* and *Dorylus braunsi* were eaten more (that is, positively selected) among the available sampled prey. This means the proportion of prey species eaten by pangolin was higher than the proportion sampled in the habitat. Among them, *Cr. Acis*, *Ph. Minima*, and *Cr.* (*Oxygyne*) sp.2 had a selection likelihood highest among all the potential prey. However, the probability of prey selections has not differed significantly among prey individuals ($p \geq 0.05$). None of the species have been used proportionally to their availability, while 10 species sampled in habitats were not ingested, including species with $W_i<1$ (see the value of Fig. 61a). The remaining species (Fig. 61b) were negatively selected meaning that pangolin has fed on a lower proportion of these species compared to their availability in the environment (as sampled in general collections).

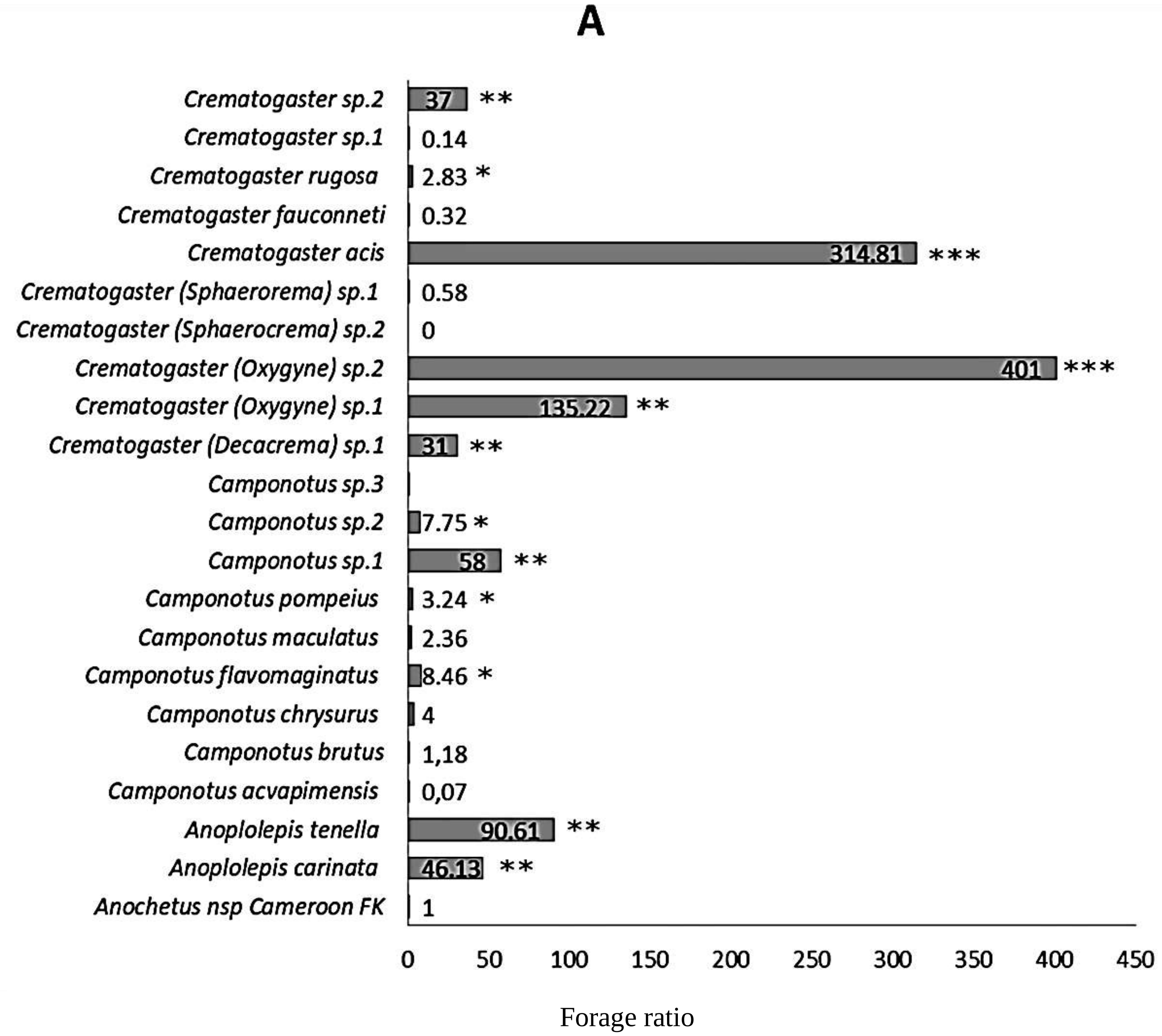
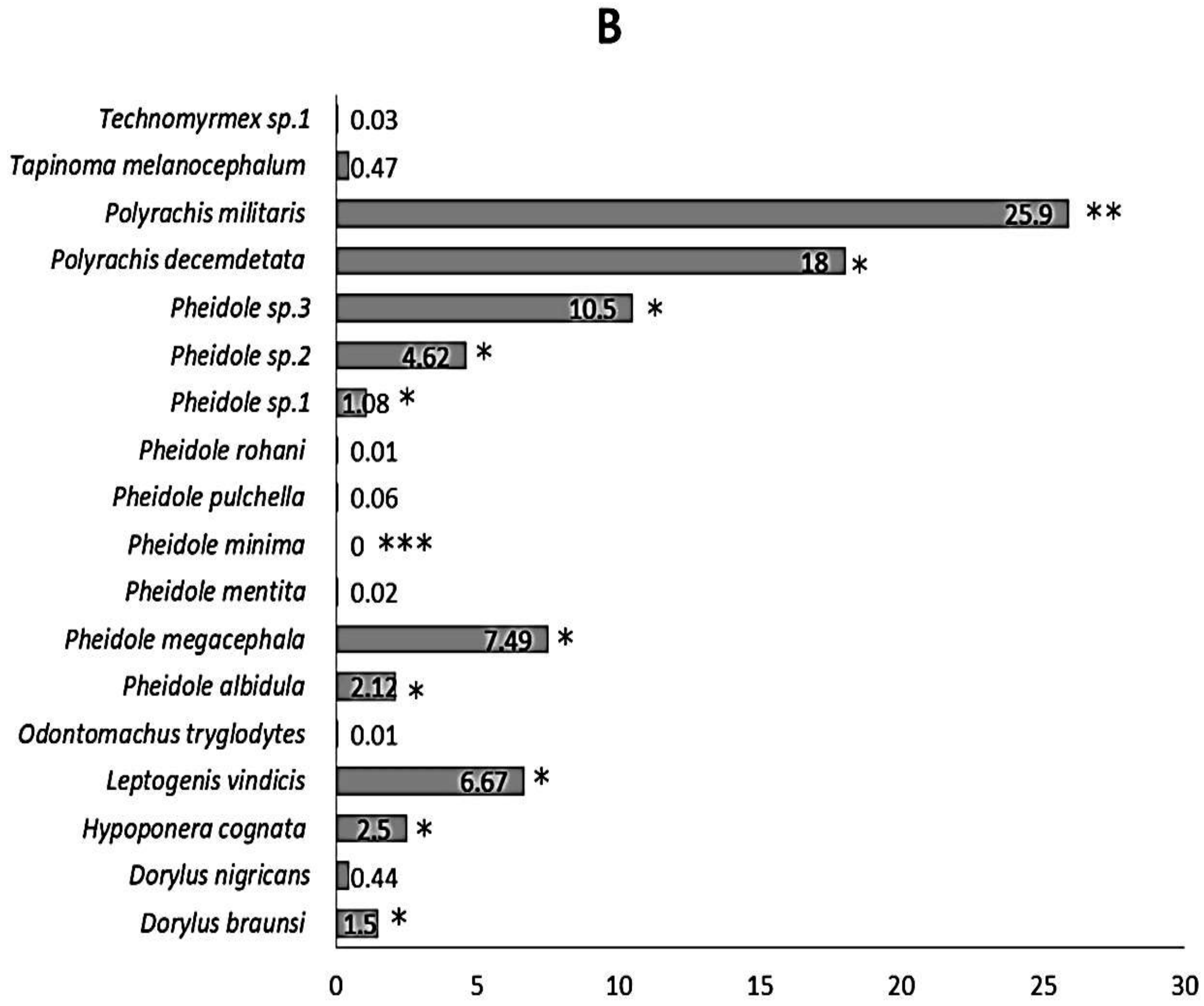


Figure 61a: forage ratios (Wi) and selection probability (Bi) of each ant prey by white-bellied pangolin showing preference. Wi values are represented by the bars and Bi with asterisks *** denote the highest probability of prey selection, ** higher probability of prey to be selected, and * lower probability of prey to be selected.



Forage ratio

Figure 61b: Forage ratios (Wi) and selection probability (Bi) of each ant prey by white-bellied pangolin showing preference other prey. Wi values are represented by the bars and Bi with asterisks *** denote the highest probability of prey selection, ** higher probability of prey to be selected, and * lower probability of prey to be selected.

III.1.4.3.1.3 Giant pangolin preys' selectivity

Cataulacus weissi, *Polyrachis militaris*, *Camponotus brutus*, *Paltothyreus tarsatus,* and *Camponotus flavomarginatus* have been positively selected among the available sampled prey. This suggests that giant pangolins focused on eating certain prey species at greater rates than the prey species' availability in the environment. This is, on average, as eating social insects means that a pangolin may ingest a lot of individuals of a certain species when any given species' nest is encountered. Among these species, *Cat. weissi* and *Ca. brutus* selection likelihood was the highest among all the potential prey species. None of the species have been used proportionally to their availability, while nine species recorded in the general environment surveyed were not ingested, including species with the $W_i<1$ (see Fig. 62).

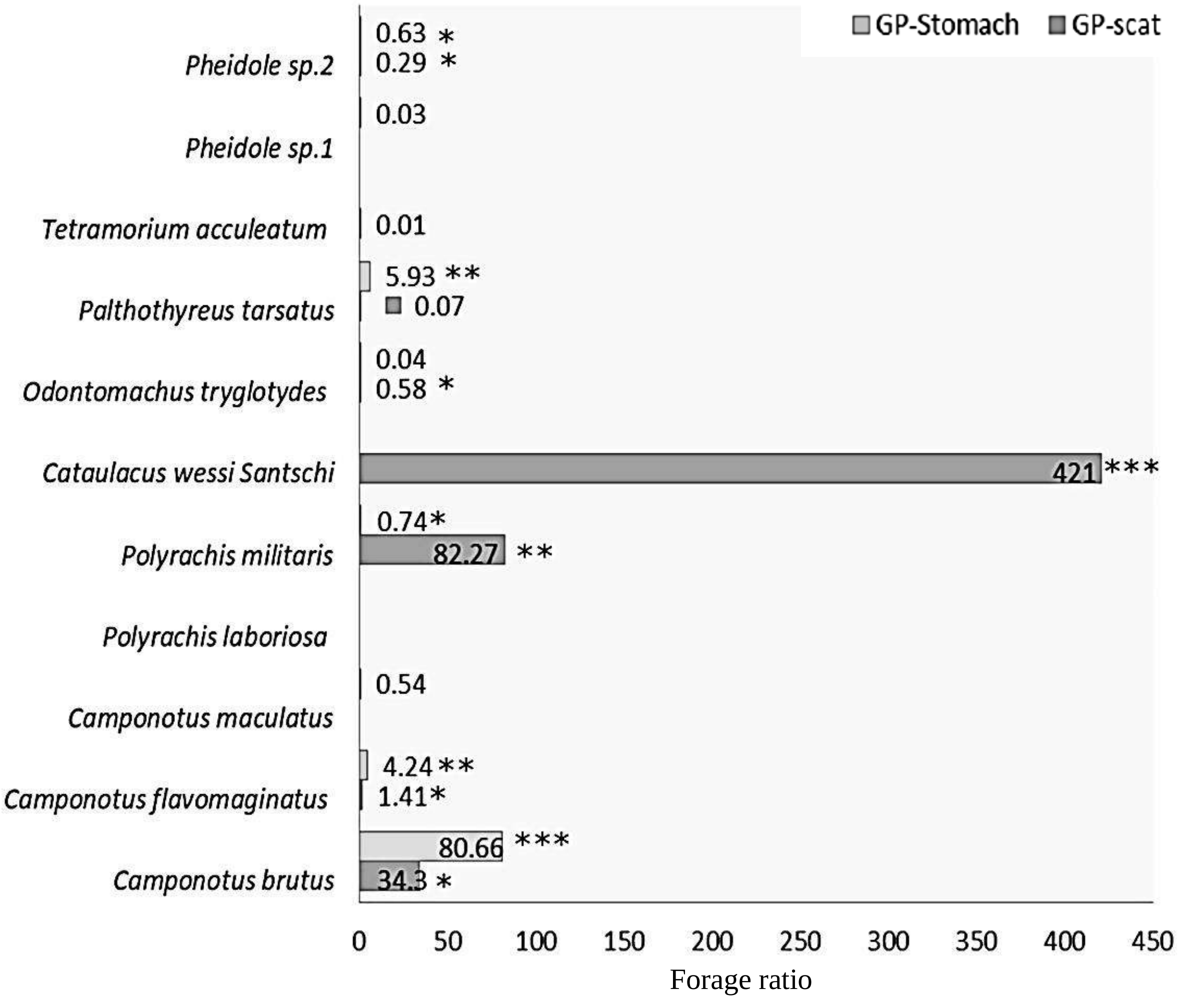


Figure 62: Forage ratios (Wi) and selection probability (Bi) of each ant prey by giant pangolin showing preference and selection. Wi values are represented by the bars and Bi with asterisks *** denote the highest probability of prey selection, ** higher probability of prey to be selected, and * lower probability of prey to be selected. GP= Giant pangolin.

III.1.5 Comparison of local ecological knowledge and documented ecology

III.1.5.1 Local people knowledge of sighting locations and documented ecology

Pangolins' local ecological knowledge (LEK) information reported by local people matched well the ecological traits gathered during the field ecological survey. The sighting locations widely reported by local people during the community questionnaire survey were targeted with camera traps and successfully recorded a high trapping rate of pangolins. Termite mounds reported by 22.1% (n=19) and burrows by 33.7% (n=29) of respondents as favorite sighting locations of GP recorded respectively 2.33% (n=6) and 7.3% (n=19) of GP detections employing camera traps. Similarly, respondents reported trees at 35.2% (n=81) and fallen logs at 34.5% (n=80) as the favorite sighting locations of WBP. At these locations, WBP's detections employing camera traps were respectively 2.62% (n=9), and 78.81% (n=268). Table LX summarizes the comparison between the

LEK of pangolin sighting locations reported by local people and the actual locations where pangolin was recorded using camera-traps.

Table LIX: Comparison between local ecological knowledge of pangolin specific sighting locations and effective recorded locations with camera traps

Habitats	Sighting locations	Giant pangolin		White-bellied pangolin		BBP
		sightings %(n)	TR	Sightings% (n)	TR	sightings %(n)
In savanna	**Termite's mounds**	**22.1 (19)**	**2.33 (6)**	**3.3 (11)**	1.45 (5)	0
	Human track	**0**	-	20.1 (74)	-	3.4 (3)
	Near farms	1.16 (2)	-	5.6 (20)	-	4.5 (4)
	Ant's nests	15.1 (13)	-	0	-	0
	Logs	0	-	3.5 (8)	-	0
	Trees	0	-	5.1 (18)	-	0
	Burrows	**33.7 (29)**	**7.36 (19)**	**0**	2.62 (9)	2.6 (2)
	Ground	24.1 (26)	2.04 (5)	12.3 (19)	-	0
	Rattans	0	0	**0**	-	2.6 (2)
	Swampy areas	11.6 (10)	-	0.8 (3)	-	0
In forest	Termite's mounds	17.1 (13)	-	6.1 (13)	-	0
	Human track	0	-	1.6 (6)	-	0
	Near farms	0	-	14.4 (53)	-	0
	Ant's nests	6.08 (9)	-	0	-	0
	Trees	**9.46 (14)**	-	**35.2 (81)**	2.62 (9)	0
	Logs	**2.70 (4)**	0.39 (1)	**34.5 (80)**	**78.91 (268)**	**0**
	Lianas	0	-	1.3 (3)	-	**0**
	Burrows	19.7 (14)	-	0	-	0
	Ground	15.5 (11)	-	15.7 (33)	15.98 (55)	0
	Rattans	0	-	2.6 (6)	-	5.2 (7)
	Swampy areas	17.1 (13)	-	10.5 (21)	-	3.2 (5)

Locations are sites of pangolins reported by local people and targeted with camera traps. Ground reported by local people refers to feeding sites on the ground targeted by camera traps, tree is tree hollows. Trapping rates of black-bellied pangolin were not computed as no detection was recorded. Abbreviations: (n) in column GP or WBP indicates the number of respondents while column TR indicates the number of independent events recorded. Dashes in rows denote that the locations were not targeted with camera traps in the habitat.

III.1.5.2 Knowledge of pangolin diet composition and documented ecology

In general, local people are familiar with the diet composition of pangolins, at least the major taxa ate. Most respondents knew perfectly that pangolins feed predominantly on ants (86.6%; n=304) and termites (79.3%; n=292) and never on herbs and leaves. We examined 14 pangolin specimens and found similar proportions of ants (60.5% -71.0%) and termites (39.0% -35.5%) in both GP and WBP stomach and scat. Pangolins could accidentally swallow sticks and leaves that were found in their stomach and scat as local people have reported these items as being eaten by pangolins. Table LXI summarizes the comparison between LEK of diet composition and actual diet composition recorded from stomach contents.

Table LX: Comparison between local ecological knowledge of diet composition and effective diet composition recorded from stomach contents.

Pangolin diet composition	Percentages of items reported		Comments
	From LEK	In stomachs	
Ants	(82.6%, n =304)	60.5 -71%; n =14	
Termites	(79.3%, n=292)	30-35.5%; n =14	
Herbs and Leaves	0	<1%; n=14	Accidentally swallow sticks and leaves
Grasshoppers	(7.1%, n=25)	<1%; n =1	Accidentally eaten
Ground	(2.6%, n=9)	<5.0%; n =14	Sands and clays were observed in stomachs and scats
Weaves	(<1%, n=1)	<1%; n =3	
Earthworm	(2.8%, n=10)	0	roundworms (nematodes) were recorded
Butterfly	(<1%, n=2)	0	
Mushroom	(1.4%, n=5)	0	Referring to termites producing mushroom that pangolin eat.
Maggots	(<1%, n=1)	0	Only one fly was recorded in pangolin stomachs

Abbreviation (n) in LEK column refers to the number of respondents and (n) in stomachs column refers to the number of individuals where the item was recorded.

III.2. Discussion

III.2.1 Local Ecological Knowledge of pangolins

The local communities living around Mpem et Djim and Deng Deng national parks had a good ecological knowledge of pangolins and their knowledge reasonably corresponds with what is observed from ecological field studies. This work shows that the black-bellied pangolin is frequently grouped with white-bellied pangolin and called *petit pangolin* in French in the study areas justifying why some percentages of respondents who correctly named the species were higher than those who recognized. Which means respondent could provide the correct name of the species even if they were not able to recognize this species not necessarily due to morphological distinction. However, the two small-sized pangolin species could be distinguished morphologically, and local beliefs differed regarding the two species. Respondents reported that giant pangolins were commonly found in savanna burrows, while the white-bellied pangolins were often seen in the forest, crossing logs, and on trees. The black-bellied pangolins were reportedly sighted on rattan palms (*Raphia* spp.) in both forest and savanna swamp habitats.

Younger respondents, aged between 25 and 35 years old, recognized giant pangolins the most among those surveyed. Increased recognition may be the result of past participation in awareness-raising and education campaigns in the younger generations. In Cameroon, the giant pangolin has been protected by law (Class A—the highest level of protection) since 1994 and this classification has led to several awareness campaigns throughout its range. Nash *et al*. (2016) suggested young people are often targeted for their interest in wildlife and conservation. Identification of black-bellied pangolin —mostly accurately done by old respondents was low amongst local people in our study, supporting its population decline over time (Ingram *et al*., 2019b). Difficulties with identifying the black-bellied pangolin were observed in other parts of Cameroon (Ichu *et al.*, 2017) and the Republic of Congo (Swiacká, 2019). This could be associated with the similar size of the two species and their ecological requirements. Furthermore, the black-bellied pangolin is mostly arboreal and its elusive behavior (likely spending most of its time in the forest canopy) might lead to rare encounters. In comparison, the white-bellied pangolin is semi-arboreal and therefore people may be more likely to observe them while walking through the forest. Confirming the presence of black-bellied pangolin is challenging, LEK-based data is sometimes considered inaccurate in the overlapping range of the black-bellied and white-bellied pangolin (Swiacká, 2019; Willcox *et al*., 2019); nevertheless, our survey has shown that cultural beliefs of wildlife may be useful factors to consider in determining possible species presence, and in distinguishing between species that are called the same locally, such as the white-bellied and black-bellied pangolins, in some cases.

Specific Location of Pangolins in the Forest and Savanna

Giant pangolins were reported in both forest and savanna habitats, and have been sighted in and around burrows, under fallen dead trees, termite mounds, and swamps, which corroborates Nixon *et al*. (2019). In the savanna, local people reported sightings at burrows, which is likely because they are a) more conspicuous in savanna habitat, and b) because the soil substrate is suitable for creating burrows, either dug by the pangolin Itself or by the aardvark (*Orycteropus afer*) (Kingdon & Hoffman, 2013). The burrow locations and presence of giant pangolins have been confirmed by a recent camera-trap survey targeted at burrows and ground-feeding sites in the savanna area. The giant pangolins reportedly seen in markets and villages, despite the species scarcity, were based only on pangolin body parts (e.g., tail, legs) prepared as bushmeat for local consumption, rather than the entire body of a living or dead individual. The white-bellied pangolin was mainly reported from several forest locations, particularly by younger adult respondents who were more likely to be engaged in hunting activities and farmers whose farms activities near forest or savanna increase their encounter rate with this species. In the forest, white-bellied pangolins were sighted walking on the ground, on lianas, and in swamp habitats, which confirms observations from previous studies (Kingdon & Hoffman, 2013; Pietersen *et al.*, 2019). Respondents also stated that white-bellied pangolins use fallen trees as pathways across the forest and that hunters place snares on these logs specifically. The white-bellied pangolin reportedly seen most recently by hunters might be due to their increasing frequency of hunting justified by the increasing international demands for pangolin scales (IUCN, 2019), during the last few years. Local people reported that black-bellied pangolins had been seen near rivers and swamps, supporting habitat preferences suggested by Kingdon (1971) and Gaubert (2011). The presence of black-bellied pangolins has been reported in farmlands described to be agricultural areas of former lowland rainforests in the southeast of Nigeria (Pietersen *et al.*, 2019), though it is uncertain if they were present in remnant palm swamps in these degraded landscapes.

III.2.2 Pangolins in both parks

III.2.2.1 Dynamism of mosaic habitats in the forest-savanna transition zone

This thesis results had shown that both Mpem et Djim and Deng Deng national parks' landscapes are a mosaic of forest-savanna habitats with a large block of forest dominant in DDNP. This is similar to previous observations from Dames & Moores (1999) and Diangha (2015). In DDNP, six types of vegetation formations were recorded, similar to previous authors working in DDNP who have described a similar subset of habitat types (see Diangha, 2015). According to Diangha (2015), the dense forest in this park is recognized by its dark green tree-colour and is physically covered by naturally humid tropical trees. Similar results were obtained in near primary forest habitats. Similar to our result, this habitat is structurally constituted of two to three floristic layers with the upper canopy reaching 85% and the understory open. However, we obtained a more largely opened canopy in near primary forest (up to 50% of canopy closure). Similar to our result, tree heights of the superior layer in this habitat ranged between 35 m to 50 m; while tree diameter at breast height was estimated within the range of 1.2 m to 2.5 m. According to previous authors, the common tree species recorded in this habitat included *Entandophragma cylindricum, Erythrophyllum ivoriensis, Hylodendron gabonensis, Pycnanthus angolensis, Triplochiton Sceroxylon, Sterculia oblonga, and Greenwaydendron suaveolens.* The author recorded mature secondary and young secondary forests. In this study, both habitat types were grouped and called secondary forests. The mature young forests are uniformly dark green and the young secondary is uniformly light green. These habitats were closely similar to the dense forest habitat described by Diangha (2015). However, the upper canopy is less dense about 75 % closure, while we obtained 25% of canopy closure in the secondary forest. Differences could be due to surveyed methods that could lead to overestimating of the canopy closure. The undergrowth has high density of shrubs, herbs and was relatively closed, similar to findings obtained by Diangha (2015) but the author found that the mature young secondary forest undergrowth where clearer when compared with the young secondary forest. The tree height of the superior layer ranged between 25 m to 35 m while tree diameters ranged from 0.9 m to 1.5 m cm. Species composition was similar to those in the dense forest habitat. This habitat type occurred in small patches spread all over the study area and was more conspicuous on the gentle slope of about 10 to 20 % in all directions. Diangha (2015) found that the most common plant species included *Uapaca guinenensis*, *Musanga cercropioides*, *Albizia zygia*, *Bateria fistlosa*, *Macaranga* sp, and *Myranthus aboreus*.

In DDNP the savanna habitats were also recorded with grassland savannah; shrubland or woodland savannah and gallery forest, similar to the result obtained by Diangha (2015). However, this author has not described the gallery forest. The grassland savannas are uniformly dense green during the rainy season and brown in the dry season with a very closed undergrowth (100% closure). It is dominated by plants belonging to family Gramineae. While woodland savanna common species mostly include *Terminalia glauscesens*, *Hymenocardia* sp, *Vitex doniana*, *Monotes kerstingii*, and *Imperata cylindrica*. This habitat forms a transition between forest and grassland habitat types. The upper canopy in this habitat was low and ranged from about 25 % closed, similar to the result obtained by Diangha (2015). Trees in this habitat reached heights of about 12 m but tree diameter is averagely low and could reach 15 cm. Except for saltwork, similar patterns of vegetation formations were recorded in the MDNP by GIZ satellite map processing. Forest is expanding into savanna, mostly in DDNP where this phenomenon is more visible (see Diangha, 2015). The lack of bushfires contributes to this spread. We observed that forest trees had weak resistance and resilience to fire and savanna trees adapt to forest environments. This is how the shifting balance is maintained in this area with different types of vegetation. These types of vegetation provided better food sources and offer the most favorable microclimate condition to wildlife.

III.2.2.2 Pangolins' presence in both parks

Giant and white-bellied pangolins

The present study shown that pangolin species have similar feeding behavior, habitat preferences, and seasonal changes in habitat use in the two localities studied. With 10,887 operational camera-trap nights accumulated in both national parks during two years, 387 pangolin events were recorded. These findings are different from Khwaja *et al*. (2019). These authors provided a cumulative trapping rate for WBP of 12.02% over 500,000 days of pangolin surveys, which is higher than our result over two years (3.26%); but lower (0.26%) if convert into our sampling effort. Our giant pangolin global trapping rate was similar to Ichu *et al.* (2017) and Bruce *et al*. (2018a) in Dja Biosphere Reserve.

Black-bellied pangolin

There is no published ecological research on the black-bellied pangolin (Willcox *et al*., 2019). To date, confirming the presence of black-bellied pangolin is challenging, but Ichu *et al.* (2017) found a carcass in Campo Ma'an National Park Forest zone during a transect-based survey and have not detected this species using camera-traps. A black-bellied pangolin carcass was found on the Nyong-ékélé divisional road located approximately 200 km from the Mpem et Djim National Park (Clinton Factheu, personal communication, March 2020; Fig. 63a) and another record from Yaoundé bushmeat market more than 300 km from survey site was made (Simo Franklin, personal observation, May 2020). Another BBP was recorded in Nki National Park on 22/02/2020 at 1:00 am in the forest from a ground-based camera-trap survey (Moppo D. Valdeck, personal observation 18 October 2020) from *Projet COMECA parténarait avec le JICA* (*Agence Japonaise de Cooperation International et l'IRAD*. At the end of this thesis fieldwork, other than the parks being located within the distribution maps for the black-bellied pangolin (Ingram *et al.*, 2019b), no other published records are available that confirm the presence of this species within the parks. However, Difouo *et al*. (2023) record a single photographic event of the black-bellied pangolin in Cameroon, this was the first record of black-bellied pangolin in Deng Deng National Park. The event was recorded in a secondary forest in the station CN14 (5°42'32.12''N; 13°50'66.89'' E: 714 m) on 21st December 2021 at 11:47 pm after 35 trap days over 63 operating days and yielded three photos. It is uncertain if the BBP climbs on the log or go down from a tree (Fig. 63b), but the pangolin walked on the fallen tree (Fig. 63b). The author obtained a BBP trapping rate of 0.063 event per 100 trap days. The probability to capture the black-bellied pangolin was low (CP=0.0006 per capture day) meaning one event was recorded after 1,571 days. The BBP capture rate CR=1.47% was similar to that of the giant pangolin recorded but lower than that of the white-bellied pangolin (CR=97,05% of all pangolin events) in that survey. Ingram *et al*. (2019c) suggested testing whether arboreal camera traps could be used to monitor black-bellied pangolins given the difficulties with using ground-based camera-trap placement due to the species near total arboreal lifestyle. LEK-based data is sometimes considered inaccurate in the overlapping range of the black-bellied and white-bellied pangolin (Swiacká, 2019; Willcox *et al*., 2019). Nevertheless, our survey has shown that cultural beliefs of wildlife may be useful factors to consider in determining possible species presence and in distinguishing between species that are called the same locally, such as the white-bellied and black-bellied pangolins, in some cases. Figures 63a and b are showing evidence of black-bellied pangolin presence in the survey areas and nearest locations.

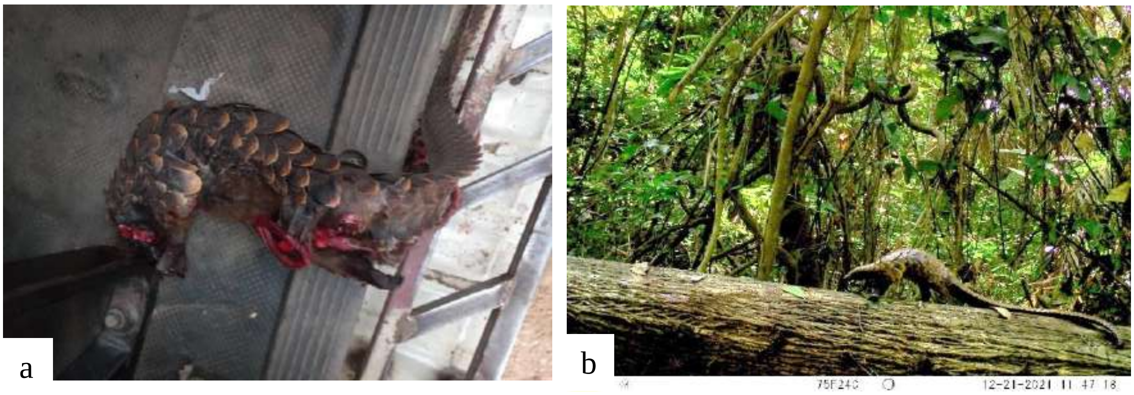


Figure 63: Evidence of black-bellied pangolin presence in the survey areas (a) black-bellied pangolin killed on road by car collision observed in the Center Region of Cameroon, (b) Black-bellied pangolin footage on a fallen log in Deng Deng National Park (East Cameroon).
Sources a: (Photo Clinton Factheu, 2020) b: (Difouo *et al*., 2023).

III.2.2.2.1 Trapping rate of pangolin species

Giant pangolin

This is the least studied pangolin. To date only Bruce *et al*. (2018); Ichu *et al*. (2017) ; Lehmann *et al*. (2020) and Matthews *et al*. (2023) surveys are available. Camera-traps have been rarely used to target specifically giant pangolins (Willcox *et al*., 2019). The trapping rate of GP in both national parks was relatively low (0.29%); our result is similar to that obtained by Bruce *et al*. (2018) in DBR (0.11%) and Ichu *et al*. (2017) (0.51%); however, Matthews *et al*. (2023) accumulated more than 24, 000 trap-days and recorded 1.12% as trapping rate. GP is known as a cryptic and elusive species that is particularly difficult to observe in the wild and has mainly been recorded opportunistically with camera traps (see Ichu *et al*., 2017). Authors suggest that covering scales of this species may reduce detection by infrared camera traps (Wahyudi &

Stuebing, 2013 cited by Ingram *et al*., 2019c). However, our camera traps have detected pangolins several times with bodies covered with mud (Fig. 64a).

Although, being highly detected in savanna habitats, GP trapping rates have not significantly differed from those in forests, especially secondary forests. Our result follows Kingdon's (1971) observations which recognize GP to occur in high rainfall secondary growth grasslands and a savanna mosaic from South Sudan. However, we have not recorded GP in near primary forests contrary to Kingdon (1971) who mentions that GP occurs in dense tropical forests, mosaic habitats, and lowland tropical moist and swamp forests. These differences remain difficult to explain since ecological factors that affect the presence or absence of GP remain unknown as well as factors affecting detection probability. As suggested by Matthews *et al.* (2023), further research utilizing data on the presence of other species, burrow morphometrics, and habitat features at the burrow location are needed to ascertain giant pangolin preferences.

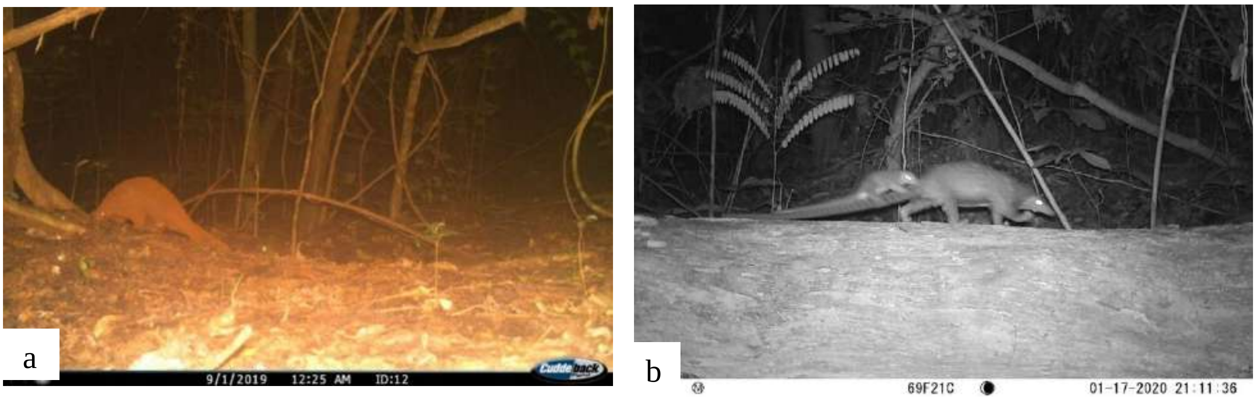


Figure 64: Some pangolin exceptional photos: (a) a Giant pangolin event showing a juvenile individual departing from a living burrow with the body covered in mud; (b) a White-bellied female carrying a juvenile on the tail
Source: Photo Ghislain F. Difouo (2022).

Our result findings have demonstrated that seasonal variation does not significantly affect the GP trapping rate. However, some habitat types recorded higher trapping rates during the rainy season, particularly gallery forest, grassland savanna, and woodland savanna perhaps due to burrows densities in savanna habitats. Our result demonstrated that the giant pangolin trapping rate is affected by the living burrow distribution which might be more often observed in some habitat types (author pers. Observation.). For example, in our surveyed areas living burrows are widely distributed in savanna habitats (Pers. Observation). These burrows are often created by Aardvark (*Orycteropus afer*) (Kingdon & Hoffmann, 2013) highly present in these protected areas' savanna habitats (from camera traps data).

White-bellied pangolin

Apart from a survey using tracking radio telemetry (Pagès, 1975), no other targeted surveys have been undertaken to assess the ecology of this species (Willcox *et al.*, 2019). This has made the comparison of our results challenging. *Phataginus tricuspis* has been mentioned by local people during interviews and observed on markets (Sodeinde & Adedipe, 1994; Soewu & Ayodele, 2009) and they are opportunistically filmed by camera traps placed on the ground (similar to Bruce *et al*., 2018). In our survey, we provided the first comparison of WBP trapping rates and found that it has not differed significantly between the two protected areas. This is perhaps due to the relatively similar vegetation formations of these two protected areas which offer similar suitable habitats and living conditions for pangolins in both parks. Overall, our trapping rate was higher than that obtained in previous surveys conducted all over the world (see Khwaja *et al*., 2019). Ichu *et al.* (2017) used a combination of diurnal sign-based surveys, community interviews; and camera-trap surveys that confirmed the species' presence with a similar but lower trapping rate (0.59%; three events). Surveys using torch spotlights have detected only a few numbers of pangolins (Pietersen pers. Observation) and pangolins do not vocalize to facilitate counting populations (Willcox *et al*., 2019). Akpona *et al.* (2008) have recorded 38 white-bellied pangolin individuals in Nigeria, though no sampling effort details are provided to evaluate the detection rate. Camera-traps remains the best way to detect pangolins in the field (other than bushmeat markets for presence surveys).

Near primary forest in DDNP and secondary forest in MDNP recorded a significantly higher trapping rate than in savanna habitat types of both parks and swampy habitats. *P. tricuspis* is a semi-arboreal species occurring mainly in tropical humid forests (Kingdon & Hoffmann, 2013). This might explain low to null trapping rates recorded, respectively, in WS and GS in MDNP and GF in both parks. Season variation has not affected significantly WBP trapping rates. The near primary forest has similarly high trapping rates during both seasons, while savanna habitats (GS and WS) had low to null rates. Again, forest habitats (SF and NPF) are more favorable to the white-bellied pangolin presence and affect this species trapping rate more than seasonal changes. Likewise, Akpona *et al.* (2008) found no significant difference in population densities between plantations and natural forests and suggested that their distribution may be more sensitive to forest age than to its composition. Several factors affect Asian pangolin habitat preference such as lower elevations, gentle slope, moderate canopy coverage, reddish soil, acidic soils, the area with less human disturbance, and area having easy access to water and food by the pangolins for digging burrows (Shrestha *et al.,* 2021).

The WBP trapping rates were similarly higher during the second and third surveyed annum, but not significantly lower during the first year. The forest habitats (SF and NPF) had the highest trapping rates during the survey period, except in 2018 when the near primary forest had the highest trapping rate. Multiple habitats used in the home range might explain the slightly different observations and also possible camera-trap malfunctions during the second year. Habitat types and camera-trap placement likely influence white-bellied pangolin both probability of detection and trapping rates.

III.2.2.2.2 Pangolin behavior

Giant pangolin

Except for one event of two individuals possibly a female and juvenile, most giant pangolins observed (31 events) were solitary. A similar observation was made by Bruce *et al*. (2018) in DBR, though here they occasionally recorded mothers with juveniles and males closely and briskly following females on several occasions. In our study, the giant pangolin behaviors included mainly entering or/and exiting the burrow, inspecting burrows, foraging, or passing by the camera. Previous authors have recorded giant pangolins investigating and passing near burrows (e.g Bruce *et al*., 2018; Matthews *et al*., 2023). We recorded one video showing giant pangolin entering a burrow in the DDNP gallery forest (06 April 2020 at 00:20). At the same location the remaining events from photos show giant pangolin individuals departing from the burrow during the dry season (March 2020). Similar activity was recorded by Bruce *et al*. (2018), but the authors were uncertain if giant pangolin resides inside the burrow or not. We recorded giant pangolins departing or returning to burrows and, at times, inspecting the burrow without entering. Home ranges may overlap considerably (Matthews *et al*., 2023). It remains uncertain if different giant pangolin individuals visit the same burrows for it is difficult to recognize different individuals through photos. However, previous authors stated that several individuals used the same areas and burrow sites during the same period and that burrows are not specific to individual pangolins (Lehmann *et al.*, 2020; Matthews *et al*., 2023).

No evidence of giant pangolin feeding activity was recorded. However, the species was observed foraging near termite mounds and returning there after three days. Four GP events were recorded on termite mounds on February 25, 2020, in DDNP WS at 01:38 AM; March 13, 2020, at 02:50 AM, on September 09, 2018, at 23:49, and 01:32 AM in MDNP GF. The foraging activity was not described previously by other authors (e.g., Bruce *et al.*, 2018). In MDNP, giant pangolin has destroyed a surveilled termite mound. We found the height of the termite's mound decreasing overtime during the period in which the camera operated (34 days). As Aardvark *Orycteropus afer* was not recorded on this savanna burrow camera (90% of recorded photos) and the other three cameras were set in the gallery forests comparing. For this reason, we are confident that the feeding activity observed here was that of the giant pangolin and likely the other *Macrotermes* sp. Termite mound that we usually found destroyed in the forest (see Fig. 65).

Figure 65: Example of termite mound partially destroyed which was commonly observed in the surveyed areas.
Source: Ghislain F. Difouo (2022).

For the foraging activity recorded on active burrows, we observed that holes were often dug within an excavated termitary. This is similar to findings by Kingdon (1971) who reported that pangolins used partially open termitary as burrows for resting and feeding. Local people also reported that giant pangolin sleep and feed in burrows (see LEK result section). This fossorial feeding and resting activities may be behind the appearance that giant pangolins remain inactive for long periods in burrows, sometimes for up to weeks at a time (Bequaert, 1922; Kingdon, 1971). Foraging events were also recorded on feeding sites on decaying standing tree trunks and on termitaries. Our observations are similar to Pages (1970) who observed giant pangolins frequently visiting a series of feeding and resting sites (not well described) in its home range. Additionally, termite colonies associated with decaying wood will likely (Eggleton *et al.*, 1995; Davies *et al.*, 1999) attract giant pangolins. Giant pangolins were recorded passing near large burrows more than entering. These might be explained by pangolins using multiple burrows or some may be occupied by other species (Nixon & Matthews, unpubl. data in Kingdon & Hoffmann, 2013).

In this study, habitat type significantly influenced the giant pangolin foraging activity. The foraging activity events were observed mainly in savanna habitats, while no event was recorded in forest habitats (though giant pangolins are known to inhabit and feed in forest habitats). These results do not necessarily contradict Kingdon’s (1971) findings who state that all habitat types foraged although hillside food resources were mostly used. Although more events were observed in the rainy season, our initial findings suggest that the season has no significant influence on the activities we observed for the giant pangolin, though records were scarcer in the dry season. Our results are similar to other studies that recorded one event over 6,000 nights of camera traps in the dry season (Mills, unpubl. data cited by Hoffman *et al.*, 2020). Likewise, foraging activities of giant pangolins were low in WS and SF and not observed in all other habitat types during the dry season. Giant pangolins may use different burrows or other sites for different activities in different habitats in different nesting and resting sites in other habitats in different weather conditions. The relatively large home range of giant pangolins drives low detection probabilities and reduces giant pangolin trapping rates (Nixon, unpubl. data cited by Hoffman *et al.*, 2020). Furthermore, the high quality of resources available in the rainy season can limit the activity of species and make detection high within a smaller area and lower at a large scale. Conversely, more limited resources can increase foraging activity and increase detection probability. We observed that giant pangolins foraged actively during the rainy season in savanna habitats, supporting some author suggestions that there are seasonal differences in giant pangolin habitat use and ranging patterns (Hoffman *et al.*, 2020). Indeed, we observed giant pangolin changing their habitat use as their foraging activity was high during 2018 and 2020, while no foraging activity occurred in 2019. Observations from Nixon & Matthews (unpubl. data *in* Challender *et al.*, 2020) suggest that individual pangolins use a network of multi-species burrows located within their home range, and individual burrow use, on average, appears irregular and infrequent (see Hoffman *et al.*, 2020).

Giant pangolin's activity patterns

Although diurnal activity is commonly observed for giant pangolins (Hedwig *et al.*, 2018), within our over 32 observations, our recorded activity was mostly nocturnal extending from 7:00 to 5:00 AM. A similar result was obtained by Bruce *et al.* (2017), while Kingdon & Hoffmann (2013). Observed activities from 8:00 PM to early morning. One event was recorded at 5:00 PM, similar to some by Bruce *et al.* (2017) who recorded activity at 08:30 AM, and, in Uganda, diurnal activity is reported (Nixon *et al.*, Unpubl. data *in* Challender *et al.*, 2020). Hunting pressure impacts pangolin activity patterns for some species like elephants and chimpanzees (Krief *et al.*, 2014; Wrege *et al.*, 2010). Some species might become more nocturnal than diurnal in areas where they are heavily hunted (Hoffman *et al.*, 2020). Although based on very few numbers of independent events at several stations, we observed that species activities, such as foraging, passing, and entering and/or exiting or inspecting burrows overlap overnights with a peak of passing recorded at 00:00 AM. Reflect different individual activities behavior was observed. Few previous authors such as Hedwig *et al.* (2018); Kingdon & Hoffmann (2013) and S. Nixon *et al.* (unpubl. data) have assessed details of giant pangolin activity patterns. However, Bruce *et al.* (2017) recorded activity peaking at 4:00

AM. Foraging events that we observed often began around 7:00 PM, likely being the beginning of food searches that extend throughout the night. Giant pangolins we observed inspecting burrows and then entering and/or exiting the burrows typically were doing so between 11:00 PM and 00:00 AM. This tentatively suggests a timing of 4-5 hours of activity before returning. The activity of a pangolin appearing at a burrow at 5:00 pm was from a single event and might not necessarily indicates diurnal activity as the species is known to be crepuscular.

White-bellied pangolin behavior

Most of the time white-bellied pangolin was recorded as solitary individuals. Solitary behavior is commonly mentioned, except during mating and young-rearing periods (Challender, 2009; Mohapatra & Panda, 2014; Richer *et al.*, 1997). One of our events captured a female with young, but we have not recorded two adults together (see Fig. 65b above.); Pagès (1965) found two adult individuals curled up together in tree hollows, perhaps male and female during the mating period.

White-bellied pangolin activities that we observed were mostly eating, foraging, or passing and, rarely, entering or exiting the burrow and marking soil, all these activities were previously observed by others (see Kingdon & Hoffmann, 2013; Jansen *et al.*, 2020). Scent marking and entering in burrows rarely recorded were also previously observed by Bruce *et al*. (2017) and Pagès (1968). Pangolin feeding behaviors (e.g. passing, eating, foraging activity) were significantly higher than scent marking and entering burrows which are more territorial, resting, and nesting behaviors. Similar behavior was observed by Jones (1973) who reported the species is most active nocturnally; devoting most of its active time to foraging for prey and resting only during the daytime (see Jansen *et al*., 2020).

Target type significantly affects foraging and feeding activities. WBP primarily fed (88 events) and foraged (45 events) in the dead trunk with termites (DTWT); similar results were obtained by Kariwata et al. (2020). The authors found that foraging events of Indian pangolin on termite-infested logs were highest than on other targets apart from a termite mound in forested habitats. We found the species fed rarely on ground feeding sites (GFS) and feeding sites on standing trunks (FSST). Dead tree trunks with termites favored by WBP for feeding activities are termite-infested logs located at a mid-strata level between ground level and tree canopy in the forest which might attract the pangolins. Pagès (1975) and Alempijevic (unpubl. data *in* Challender *et al*., 2020) recorded foraging activity mostly on the ground in Gabon and in DRC, in contrast to Benin, where Akpona *et al.* (2008) observed the species foraging largely in trees. Our survey suggests that WBP pangolin might forage both in trees and at ground level, as known to feed on arboreal and terrestrial ant nests and termitaria (Pagès, 1975). This is supported by the ant species we observed in the species' stomach contents being known from both tree /and ground prey.

Habitat type significantly affects WBP activities and, especially, feeding activities with a higher foraging rate in SF (27.25%; 109 events) than in NPF (5%; 20 events) and WS (0.5%; two events). Secondary forests might provide a greater abundance of ant and termite colonies for pangolin foraging, such as decaying fallen logs and tree species which attract ants and termites in large quantities (Odemuni & Ogunsina, 2018). Our results are different from Akpona *et al.* (2008) who observed foraging activity occurred mainly in semi-deciduous forests and found no difference in encounter rates between natural forests and plantations and the Democratic Republic of the Congo (DRC) in the regenerating forest comparable to the secondary forest (Alempijevic, unpubl. data *in* Challender *et al*., 2020).

White-bellied pangolin (WBP) feeding activity was recorded more significantly during the rainy season and they were observed foraging more in the dry season. Pagès (1975) observed similar trends in foraging activity, reporting that activity of WBP varies by season with individuals foraging more in the dry season (see Jansen *et al*., 2020). High foraging activity in the dry season might be due to a lack of food availability which increases foraging effort rather than prey abundance. Wet season abundance of food might reduce foraging (food searching) and increase feeding. WBP passes cameras at the same rate in rainy and dry seasons suggesting different or the same individuals travel between several foraging sites located in different habitat types. During the rainy season, WBP fed in the feeding site on a standing trunk, ground feeding site (13 events), dead trunk with termites (88 events), and termite mound, the same site where they forage.

White-bellied pangolins' activity patterns

White-bellied pangolin recorded events were exclusively nocturnal, similar to observations by Pagès (1975) and Bruce *et al*. (2017), though the species has been observed to be active in the day (Jones, 1973 cited by Jansen *et al*., 2020). Activity periods extended from 7:00 PM to 5:00 AM, particularly for foraging activity widely described by Pagès (1975) which usually started at 7:00 PM and extended to 4:00 AM. Foraging activity overlaps with eating activity which shows three peaks. Several peaks of activity belong to different individuals of different sex and age and might reveal segregation in activity time in the surveyed areas as suggested by Pagès (1975). Our results are similar to that of Pagès (1975) who found the species active between 7:00 PM up until 04:00 AM with sex and age affecting foraging time. Likewise, the species was active between 8:00 PM and 04:00 AM in Dja Biosphere Reserve (ZSL, unpubl. data *in* Challender *et al*., 2020) and between 6:00 PM and 05:00 AM with a peak of activity at 03:00 AM in Lomami National Park (DRC) (Alempijevic, unpubl. data *in* Challender *et al*., 2020). There are spatial and individual factors affecting white-bellied pangolin activity periods. Different temporal peaks were observed for different individuals. Pangolin passing activity recorded covers a wider period from the first hour of activity (7:00 PM) to early morning 5:00 am, suggesting they may be departing or returning from their daily resting site. Passing periods peaked four times and include two foraging peaks. These observations reflect the individual variation and segregation of activity patterns. In the other words, the different individual does forage at the same hour meaning some continue foraging when others were returning or departing from their foraging sites.

III.2.3 Potential insect prey in pangolin habitats

III.2.3.1 Ants diversity

This study confirmed that potential ant and termite preys of pangolins are present in Deng Deng and Mpem et Djim national parks and their occurrence and diversity change in different habitat types and seasons. In fact, our survey has recorded more ant species richness than the previous prey assemblage surveys conducted by Pietersen *et al.* (2016); Swart *et al.* (1999) using similar approaches and more sampling effort. But lower than the number of ants obtained in other protected areas (Deblauwe & Dekoninck, 2007) and in different land use management system (Tchoudjin *et al.*, 2020) in Cameroon. Tchoudjin *et al.* (2020) recorded a higher species richness (306 ant species) perhaps due to continuous sampling combining different techniques with sufficient sampling effort across different seasons and years. This strategy has proven effective to increase the number of species collect over a survey period and to record rare species. For both national parks and habitat types surveyed, the ant and termite species rarefaction curves suggest a good portion of the fauna of each was sampled comparable to other related surveys (Felicitas *et al.*, 2018; Mbenoun *et al.*, 2021; Tadu *et al.*, 2014; Tchoudjin *et al.*, 2020). Near-complete sampling of ants is challenging due to rare, cryptic, and rarely detected species (Gotelli *et al.*, 2011).

Subfamilies

Previous studies have found that Myrmicinae was typically the most species-rich subfamily of ants in tropical ecosystems (Ward, 2010; Hölldobler & Wilson, 1990; Tadu *et al.*, 2014; Tchoudjin *et al.*, 2020). The high species richness recorded in the Myrmicinae subfamily might be due to their ecological requirements such as their wide variety of feeding and nesting habits making them the most species-rich subfamily of ants in tropical ecosystems (Cerda *et al.*, 2012; Marsh, 1984). This was the case for the primary closed-canopy forests of the Dja Biosphere Reserve to the south of MDNP and DDNP (Deblauwe & Dekoninck, 2007). This trend was observed in DDNP; however, our samples in MDNP had Formicinae as the most species-rich subfamily. Vegetation structure can influence terrestrial invertebrate communities and abundance by providing niches or plant foods (Woodcock *et al.*, 2010). Formicinae were being also speciose rich and commonly recorded, perhaps due to the sampling regime particularly effective at detecting large-sized cursorial ants (Olson, 1991). The preponderance of Ponerinae is typical for these opportunistic foragers that use many different habitat types (Tadu *et al*., 2013, 2014).

Genera

The most species-rich genus in MDNP was *Crematogaster* and *Tetramorium* in DDNP. Deblauwe and Dekoninck (2007) similarly recorded *Tetramorium* to be the most species-rich in the Dja Biosphere Reserve. And in different land use management systems (Tchoudjin *et al*., 2020). These results could be explained by the fact that the species in this genus are very aggressive, and their large numbers could lead to interspecific competitions for space (Deblauwe and Dekoninck, 2007; Tchoudjin *et al*., 2020). However, *Crematogaster* was the most speciose ant genera in MDNP perhaps because this park vegetation is instead a forest-savanna mosaic habitat where forest and savanna habitats alternate. Our result differs from that obtained by Deblauwe and Dekoninck (2007) in the mature moist tropical forest and Tadu *et al*. (2013, 2014) in a disturbed agroforest system in Cameroon.

Species

The most frequently sampled ant species in most habitat types in both MDNP and DDNP was *Palthothyreus tarsatus,* similar to observations of Kalule & Banage (1977). This species forages in groups over large areas which may increase their capture rates (Tchoudjin et al., 2020). In general, the relative abundance of different ant taxa in the samples reflects patterns observed for other Central African forests and savannas (Mbenoun et al., 2021). *Pheidole* sp. was the most common species collected by Swart *et al.* (1999). The differences observed are likely due to the sampling regimen we used that favors larger cursorial ants often represented by Formicinae and Ponerinae (see Olson, 1991) which increase the probability of collecting most of the species in a habitat (Ward, 2010). The diversity of the habitat types in MDNP mostly forest-savanna mosaics providing suitable habitat for all native ant species. Our success in species sampling demonstrated that either in parks or habitat types we have sampled between 60-90% of extant species. Total local ant species richness from all our samples was far higher than in many habitat types.

Variation among habitats

The results presented in this thesis clearly show that sampling location (parks) and habitat types significantly affect ant species richness with the highest richness recorded in mature forest-dominant protected areas (DDNP) and habitat (NPF and SF) and lower in flooded habitat (swamp and saltwork). Ant species are not uniformly distributed across the earth. Lowland forests are known to have the world’s most diverse ant communities (Ward, 2010). There is a strong latitudinal gradient in species richness with the tropical forest containing far more species (Ward, 2000). This study shows that ant communities were significantly more diversified in the relatively mature and lower disturbed forests of both parks which might offer more favorable conditions for ants compared to savanna. With a specific floristic composition, secondary forests in which their tree leaves provided nest and forage sites such as nectar and also some insects captured on the flowers for ants feeding (Tchoudjin *et al*., 2020). Ant diversity was highest in primary and closed-canopy forests and lower in swamps, the latter perhaps caused by intermittent flooded conditions (Ellis *et al*., 2001, Majer & Delabie, 1994 cited in Deblauwe & Dekoninck, 2007). Indeed, the permanent hydrological conditions of swamps generally reduce the diversity of ant species similar to termites (Posa *et al*., 2011). Ant assemblages in savanna, woodland, and gallery forests were more similar to each other than that of the near primary and secondary forests. Near Primary Forest, the most mature habitat of the surveyed areas yielded a significantly higher mean abundance of individual ant species similar to patterns observed by Deblauwe & Dekoninck (2007). Except for the Near primary forest, the secondary forest had more ant species than other habitat types in DDNP. Our results are in accord with Wenninger & Inouye's (2008) findings that there is a significant effect of vegetation types and habitat disturbance on ant species richness and abundance. However, all habitat types in MDNP yielded similar species richness, perhaps due to the plant species richness and composition, and their physical complexity (mostly forest-savanna habitat) which plays an important role in determining ant assemblages (Majer & Nichols, 1998 cited by Deblauwe & Dekoninck, 2007). It is known that, in general, the diversity of plant communities is one of the major environmental factors that influence species diversity by shaping the resource availability to the soil community (Anderson, 1978).

III.2.3.1 Variation of ants' occurrence

Myrmicinae was the most commonly sampled subfamily in this study, similar to the previous survey in the primary closed-canopy forests of the Dja Biosphere Reserve located southward of MDNP and DDNP (Deblauwe & Dekoninck, 2007) and in different land use management systems (Tchoudjin *et al*., 2020) in Cameroon. This result might be because Myrmicinae is the most species-rich subfamily of ants in tropical ecosystems, and their dominant status in several terrestrial habitats (Marsh, 1984) and their ability to adapt to changing environmental conditions increase their likelihood to be sampled (Savitha *et al*., 2008; Ward, 2010). However, in this study, some samples in MDNP had Formicinae or Ponerinae as the most common subfamily perhaps due to the different types and ages of habitats between the two parks. MDNP is dominated by young secondary forests (36.5% of vegetation formations), with Closed undergrowth which is the favored habitat for Formicinae (Tchoudjin *et al*., 2020), while DDNP is dominated by primary closed-canopy forests (Diangha, 2015), the most speciose habitat type for ants in tropical ecosystems (Ward, 2010). Ponerinae was also dominant perhaps due to their opportunistic forager behavior which makes them able to evolve and adapt in different types of habitats (Tadu *et al*., 2013, 2014). We obtained different subfamilies dominating ant communities in MDNP and DDNP because the sampling regime that we used is more likely to detect larger cursorial ants often represented by Formicinae and Ponerinae (Olson, 1991), and also increases the probability to collect most of the species in a habitat (Ward, 2010). *Camponotus¸ Polyrachis*, *Odontomachus, Tapinoma*, and *Pheidole* were among the most frequent genera recorded by Wilson (1976) and Tchoudjin *et al*. (2020) similar to this study. These results might be explained by the fact that *Pheidole* is an abundant ant genus, and their species' aggressiveness and territoriality may contribute to their dominance in the leaf litter, while *Camponotus* forage generally solitary and disperse in large surfaces increasing their trapping with pitfalls (Wilson, 1976). The single most frequent ant species in most habitat types in both MDNP and DDNP, *Palthothyreus tarsatus* is a locally abundant and forager ant species (Kalule & Banage, 1977). *Pal. Tarsatus* is among the most frequent ant and its high dominance may be explained by its opportunistic behavior that facilitates its adaptation to various environmental conditions as suggested by Tchoudjin *et al*. (2020).

III.2.3.2 Termites

In this thesis, more termite species were recorded than in Felicitas *et al.* (2018) in the different land-used management systems (69 species) and other prey assemblage surveys in arid and mesic zones (4 species) in South Africa (Pietersen *et al.*, 2016; Lindsey, 1999) and diversity survey in forest zone (88 species) (Eggleton *et al*., 1995), perhaps because we conducted targeted sampling (1) on termite microhabitats increasing probability to collect a large number of species, and (2) in mature habitat in the forest with relatively closed canopy known to be associated with rich species assemblages (Dibog *et al*., 1999; Eggleton *et al*., 2002). However, Deblauwe *et al.* (2007) and Eggleton *et al*. (1995) recorded higher termites' species richness respectively in the Dja Biosphere Reserve and forestry reserve of Mbalmayo in Cameroon perhaps due to the sampling technique which favoured a higher number of subway-solderless termites (Apicotermitinae). These authors have continuously sampled termites in similar but more mature-habitat types in different seasons using different methods which can increase species richness and record rare species.

Families and sub-families

Termitidae was the dominant and speciose termite family with 99% of the total species recorded from both reserves while Rhinotermitidae was the least common; similar results were obtained by Felicitas *et al*., (2018). This result is a similar finding to that of Couto *et al*. (2015) and Felicitas *et al*. (2018) for other tropical forest areas. Previous authors suggested that Termitidae dominance is mostly due to their strong adaptation on cellulosic sources other than wood (Inward *et al*., 2007). Macrotermitinae is the dominant subfamily in both protected areas, followed by Cubitermitinae. This is a similar finding to that of Couto *et al.* (2015) and Felicitas *et al*. (2018) for other tropical forest areas. It is a fungus-growing group of termites widespread in tropical moist forests. Cubitermitinae was also common, their mounds are widespread in savanna. The soldierless termites Apicotermitinae were uncommon in our samples likely because they generally build no nest structures and live in tunnels (Bignell, 2011) which make sampling species of this subfamily challenging unless using soil-sampling methods (Eggleton et al., 1995).

Genera

The most species-rich genus in both parks was *Isognathotermes* followed by *Microtermes* and *Macrotermes*. Similar results were obtained by Felicitas et al. (2018) who recorded *Microtermes* and *Macrotermes*, as the most dominant genus. *Isognathotermes* is the most frequent genus of Afro-tropical forests termite mounds (Bachelier, 1973) and therefore was among the most sampled. While *Microtermes* are wood-feeder species building galleries on tree trunks and negatively affecting productivity in forest-transition zone (Felicitas *et al*., 2018).

Species

The most frequently encountered species in most habitat types were *Ancistrotermes crucifer* and *Pseudacanthotermes militaris*, two wood feeding termites. These are widespread pests of crops in tropical ecosystems (Bignell, 2011; Felicitas *et al*., 2018). Predominance of both species may reflect the abundance of dead wood and leaf litter in the surveyed areas (Eggleton et al., 2002).

Variation among habitats

Termites were most species-rich in closed-canopy and low-disturbed habitats in both protected areas (Near primary forest, secondary forest, and gallery forest), similar to observations of Felicitas and colleagues (2018) and de Paula *et al.* (2016) for other tropical forests. Our results corroborate previous observations on the diversity of termites which decreases along a gradient of deforestation from the primary forest to the secondary forest (Davies *et al.*, 2003; Eggleton *et al*., 2002). It might be also due to the different conditions between forest and savanna habitats. According to Dibog *et al*. (1999) and Eggleton *et al*. (1995; 1996), habitats with greater canopy cover (e.g., primary forests) are areas where the species richness of termites is more important. Likewise, primary forests are known as large hotspots of biodiversity (Pelissier, 2010). The local species richness of termite assemblages is influenced by local environmental factors including rainfall, vegetation type, temperature, and altitude as well as an anthropogenic disturbance (Davies *et al.*, 1999). Additionally, the secondary forests consist of a mosaic of different decay rates of dead wood, allowing the occupation of a variety of small-scale microsites by various termite species

(Eggleton *et al*., 1995, 1997). This dead wood, left on the ground, accelerates the recovery of termite assemblages and total diversity (Davies *et al.*, 1999).

Variation of termites' occurrence

Few targeted surveys have been undertaken to assess the frequency of occurrence of termite species. This has made the comparison of our results challenging. We found that Macrotermitinae, Cubitermitinae and Nasutermitinae were the most common subfamilies; a similar result was obtained by Eggleton *et al*. (1995). This result might be explained by the fact that Macrotermitinae is fungus-growing termites widespread in tropical moist forests, while Cubitermitinae dominance could be explained by the fact that, termite mounds (their favoured nest) were the most common sampled microhabitats in the surveyed habitats. Termite assemblage composition shows a strong response to habitat disturbance and may be indicative of quantitative changes in the decomposition process (Jones & Eggleton, 2000). *Isognathotermes* was the most commonly sampled genus of Cubitermitinae, perhaps because they are the genus most commonly encountered in termite mounds in tropical forests (Bachelier, 1973). The solderless Apicotermitinae was uncommon because they generally build no obvious nest structures and appear to live in a set of amorphous tunnels (Bignell, 2011) which makes them difficult to be sampled unless using soil-sampling methods (Eggleton *et al*., 1995; Felicitas *et al*., 2018). The single most frequent species encountered in most habitat types were *Ancistrotermes crucifer* and *Pseudacanthotermes militaris*, a wood-feeder termite that is a pest of crops widespread in tropical ecosystems (Bignell, 2011). This result could be explained by the strong presence of dead wood and leaf litter constituting the ideal shelters for this species in our surveyed area.

III.2.4 Pangolins' diet composition and prey selectivity

As predicted on the dietary trend of the three species of pangolins in Cameroon, this study found that giant pangolin and white-bellied pangolin species have different diet compositions and prey selectively on different sets of ant and termite species. Our results shown that there are seasonal differences in the prey selectivity of white-bellied pangolin species.

III.2.4.1. *Phataginus tricuspis* diet composition

Our survey demonstrates that the stomachs of white-bellied pangolins contained a high proportion of undigested insect individuals (ca 90% of total weight), similar to our result obtained from a giant pangolin juvenile stomach analysis and the result from Lee *et al.* (2017). However, different results were obtained by Ashokkumar *et al*. (2017), and Karawita *et al*. (2020) in pangolin scat analysis and also for the giant pangolin scat analyzed in this study. These authors recorded undigested insects in more low proportions comparable to that we obtained stomach contents and in giant pangolin scat examined. The differences might be due to the methodological approach. These authors examined scats (final digestion product), while stomach content samples that we examined were mainly not yet digested. Likewise, they recorded a higher proportion (ca 57% and 9.8% of total weight) of grit and plant matter than in this survey. Grit (sand, stone) and clay which are present in the stomach play a mechanical role in the digestion process; they have been identified as an important constituent of the pangolin diet as help mechanical digestion and are supplementing essential mineral nutrients (Irshad *et al*., 2015). The differences in the plant matter ingested might be due to the habitat conditions where the two studies have been carried out, and the variety of foraging target options available, especially in the tropical rainforest-associated habitats as suggested by Karawita *et al*. (2020). Other invertebrates recorded, such as Coleoptera and Hemiptera, Diptera, and Arachnida according to their relative importance might be accidentally ingested by pangolin, while Nemathelminthe and Mites are parasites as suggested by Ntiomoa-Baidu *et al.* (2005).

In all the stomach contents examined, the ants were more abundant, 60.34% of the insects inventoried; a similar, but higher proportion of ants (96.0%) was recorded by Swart *et al*. (1999) in temminck ground pangolin and (96.94%) by Lee *et al*. (2017) in Chinese pangolin. Five ant subfamilies (dominated by Myrmicinae and Formicinae) were recorded in the stomach contents examined; these two subfamilies were the most commonly sampled in habitats during this survey. The subfamily Myrmicinae is known to be the most diverse and dominant ant group in various ecosystems (Marsh, 1984) and therefore might be more available as food resources. Formicinae are known to be mostly arboreal; this might make them more accessible to white-bellied pangolins. Among the other subfamilies, including Dolichoderinae, Ponerinae, and Dorylinae, only Dorylinae was recorded by the previous author (Kingdon & Hoffman, 2013). The white-bellied pangolin diet was species-rich, comprising 101 species and 23 genera ([92.0% of sampled genera]). These results remain greater than those reported by Pagès (1970) and Pagès (1975) cited by Kingdon & Hoffman (2013), and Pietersen *et al*. (2016) who, during their various surveys, had reported only two termites and six ant genera, respectively. The high diversity and percentage of prey species items recorded in WBP stomachs might be due to the semi-arboreal lifestyle of the white-bellied pangolin; the species is known to forage both on the ground and in tree canopy Pagès (1975), Akpona *et al.* (2008). Additionally, habitat types significantly affect ant species percentage with the highest richness recorded in mature forest-dominant protected areas (DDNP) and habitat (near the primary forest and secondary forest) and lower in flooded habitat (swamp and saltwork) as observed in this survey. Thus, the overall high diversity of prey recorded and the difference in prey percentage between pangolin individuals could be also explained by the type of habitat where the pangolin fed last time. Pangolin individuals examined were collected from different habitats in a forest-savanna mosaic habitat which is not specified. In terms of composition, eight ant genera (35.8%) were more frequently eaten by white-bellied pangolin individuals. These include *Crematogaster*, *Camponotus*, *Leptogenys*; *Pheidole*, *Polyrachis, Anoplolepis, Formicidae* sp. 2, and *Monomorium*. And five genera (21.73%) were less frequently eaten, including the same genera recorded by the previous authors, except the genera *Myrmicaria* that was recorded in previous studies only (Kingdon & Hoffmann, 2013). These differences might be related to the type of study and/or the sampling methods employed. We examined stomach contents which might be more effective to determine an animal diet composition (e.g., Mohamod *et al*., 2013; Lee *et al*., 2017; Ashokkumar *et al*., 2017). In terms of the proportions of main prey groups consumed, our results are similar to previous authors (Pietersen *et al*., 2016; Swart *et al*., 1999) and also those of giant pangolin in this study. The predominance of ants in pangolins was observed by previous authors. High abundance and wide distribution of ants in various habitat types make them available to predators as food resources (Redford, 1987; Fernandèz & Delsinne, 2013).

The termites recorded in thirteen WBP stomach contents were less abundant than ants (39.95% of the insects recorded). These results are higher than those from Lee *et al*. (2017) and similar to those from giant pangolin where almost 30% of insects from the stomach contents of a giant pangolin had been termites. Similar results have also been observed in studies in South Africa and East Africa (Swart *et al*., 1999; Pietersen *et al*., 2016). Eight termite subfamilies (largely dominated by Macrotermitrinae and Nasutermitinae) were recorded in the stomach contents examined; these two subfamilies were the first and third most commonly sampled termite subfamilies in habitats during this survey. Previous authors had mentioned similar subfamilies as being part of the WBP diet (Kingdon & Hoffman, 2013). We recorded 16 termite genera, including four commonly or preferentially eaten (e.g *Nasutitermes*) and another four uncommonly or secondarily eaten. Kingdon & Hoffman (2013) reported only two genera of termites (*Nasutitermes* and *Microcerotermes*). Likewise, for ants, the type of study and the methodological approach might drive the differences observed. According to Redford (1987), ants are eaten in large numbers compared to termites due to their low nutrient value. The low observed abundance could be explained also by the phenomenon of differential digestibility (Pierce & Boyle, 1991). Indeed, the chitinous coating of some ants may be hard to digest, such as the head which is leatherier (hard) than that of termites (Mahmood *et al*., 2013). This may explain the high number of undigested ant heads in the stomach contents. However, the results could simply reflect the number of ants and termites consumed during the last meal of each pangolin as observed from the giant pangolin.

Among the 13 stomach contents analyzed, the contents of WBP01 and WBP08 contained significantly higher abundance of ants, while those of WBP11 and WBP13 were less abundant. These low observed abundances and differences among individuals are similar to those obtained by

Loomis et al. (2010). Caution should be applied to comparisons of abundances of insect prey between pangolin individuals. Several limitations are inherent to the analysis of stomach contents because some observed prey remains are often heavily digested while others are not (pers. Observation). Karawita et al. (2020) found that the digestibility of the head, mouthparts, abdomen, and legs of the ants was significantly lower than that of the termites, whereas undigested termite wings were frequently observed in the faecal matter of Indian pangolin (*Manis crassicaudata* É. Geoffroy, 1803) compared to the wings of ants. In general, most of the body parts of the termites are digestible compared to the body parts of ants. This could be a source of bias in the quantitative assessment of the number of prey species consumed by one individual. Thus, the abundance of species with large numbers of prey species that cannot be fully digested (e.g., ant heads) might be overestimated in the diet compared to small species without hard parts or completely digestible (e.g., juveniles, eggs, or some small termites). Moreover, the time between last feeding and death of pangolins also impacts the digestion level in stomach and the quality and quantity of prey species found there. In other words, the retention time in the stomach of food is not the same for all the examined pangolin individuals and for all types of parts. The head of termites and ants are heavily chitinous and are difficult to full digest. They were counted in this survey as the only items of our abundance estimation. According to Swart et al. (1999), age and the ability of a pangolin to open a termite mound to get access to their resource has an influence on the abundance of prey species consumed by a pangolin. Some prey can be abundant in an environment without being available to a pangolin. For example, some *Macrotermes* species live in termite mounds that are very difficult to break for the white-bellied pangolin. The Indian pangolin is reported to favor moist termitary over dry ones (Karawita et al., 2020). In addition, it is uncertain whether the pangolin individuals being compared are of similar age or whether they forage and ate in the same location (Swart et al., 1999). In addition, other factors relating to the individual pangolins examined, such as the time between the last meal consumed and the killing, or the stress linked to the capture of the animal, may influence results. Stress can result in an over function of the parasympathetic system of the animal leading to modification of digestive secretion production processes and the mobility of the gastrointestinal tract that disturbs, the emptying of the stomach (Calvez, 2010).

Season affected differently the amount of termite and ant species eaten by pangolin individuals (although we acknowledge our sample size was fairly small), with higher ants counted in the dry season, perhaps due to more time being spent foraging in the dry season and the high abundance of ant prey available in the dry season (Pagès, 1975). Devoting more time to foraging when both small and larger-sized prey are abundant may help secure nutritional needs for reproduction (Strier, 2018). This might partly justify the high mean abundance of prey species in WBP01 and WBP08 stomach contents. Regarding the time between the last meal and the killing of the animal, the longer this time is, the more advanced would be the digestion level (Pierce & Boyle, 1991). This would be the case for WBP11 and WBP13 because few insects were in their food samples, reflecting the low average abundances observed. Resource selection is often affected by season, sex, age class, behavioural activity, and daily activity pattern of the animal (Manly *et al*., 2002). Given that ants and termites constitute a large proportion of animal biomass of many tropical ecosystems (Hölldobler & Wilson, 1990; Vasconcellos, 2010), the high volumes of both ants and termites that pangolin consume has the potential to influence the role of social insects within ecosystems (Shi & Wang, 1985 cited by Durojaye & Sodeinde, 2014).

Variation of prey eaten by white-bellied pangolin individuals

The composition of prey genera eaten by WBP varied slightly between individuals. For example, we found three pangolins mostly fed on a similar set of ant and termite genera *Nasutitermes, Monomorium, Termitidae gen.*1, and *Formicidae gen*.2. Two other pangolins largely fed on *Anoplolepis* ants and *Macrotermes* termites as their most abundant prey. The latter two individuals may have foraged in similar habitats or simply encountered concentrations of these species in their foraging as suggested by Pagès (1975) cited by Jansen *et al*. (2020). Six other pangolins consumed combinations of the ant and termite genera *Camponotus*, *Odontotermes*, *Polyrachis*, *Formicidae gen.2*, *Pseudacathotermes*, *Pheidole*, and *Crematogaster.* Most of the examined pangolins (10 individuals over the 13 examined) commonly consumed more than six species. *Anoploepis tenella* and *Pheidole minima* were strongly associated with WBP10 more than the other pangolins. Our results may only reflect the species consumed and behaviors of the pangolins during their last feeding event (on particular insect nests and in a particular habitat) rather than any preference or targeting of prey species by pangolin individuals (see the section on prey selectivity). Based on their last meals, the data suggest that different WBP individuals might forage opportunistically on the prey they encounter, though they may seek out in a general way and spend more time consuming on preferential prey genera and species as observed by Kalmbach (1944) cited by Redford (1983).

Similarity of termite and ant prey-specific composition in pangolin meals

The WBP individuals can share up to 15 prey species over 101 species that were documented as prey in this study and 36 species eaten by one individual. They displayed low similarity between pangolin individual meal compositions. However, for termites, almost all pangolin individuals ingested termite species compositions were highly similar with up to 12 termite prey eaten commonly (over a maximum of 13 termite species during the same individual meals) by thirteen individuals of a documented total of 33 species. There presently is little data in the literature on differences in the diet of white-bellied pangolins due to animal age, size, or sex to enable comparison.

White-bellied pangolin prey selectivity

For termites, the WBP mostly fed on nine termite species including small (<5 mm), medium (8 mm), and larger (16 mm) sized species. This result is different from that obtained for the giant pangolin here and that recorded for Temminck's pangolin (Pietersen *et al*., 2016) who found only one termite prey eaten by this species. It appears that some examined pangolin individuals have selected large-size prey with a higher probability of selection (*Macrotermes bellucosus*) and on contrary avoided similar-sized species, for example, *Macrotermes amplus*, perhaps because this species might be less accessible/ abundant or has strong defense mechanisms or even has intensive or slow mobility or has low nutrient value as suggested Swart *et al*. (1999) and Lindsey (1999). The mobility or activity pattern of prey species can rapidly reduce or increases the prey density at the feeding site, while highly abundant prey species might be more likely to be selected than low abundant prey (Lindsey, 1999). Similarly, the nocturnal activity of *Macrotermes albopilosum* probably decreases temporal availability as prey to the aardvark by decreasing the concentration of ants in the nest (Lindsey, 1999). Given the similarity of the calorific values of the various species, one might expect the size of the various prey species to be of significance in prey choice (Lindsey, 1999). Moreover, they appear to avoid some small-sized species, including *Microtermes osborni* and *Microcerotermes silvestrianus* which are wood-feeders, and *Isognathotermes kemnri* which is a soil-feeder that might be difficult to harvest in great numbers and therefore, provides a low quantity of nutrients. This suggests that the white-bellied pangolin is an opportunistic feeder on a set of larger, more available termite prey species. However, abundance might not be the unique factor determining prey's selections. Lindsey (1999) suggested that activity patterns of the prey species may be of some importance in determining the level of utilization of some prey by the aardvark. *Hodotermes mossambicus*, for example, exhibits unpredictable activity patterns as an anti-predator strategy (Wilson & Clark, 1977). Resource selection is also often affected by season, sex, age class, behavioural activity and daily activity pattern of the animal studied (Manly *et al.*, 2002).

For ants, white-bellied pangolin ant preys' range is very large, including mixed ants of different sizes from very small ants of (<1 mm) to small (2-3 mm), medium (8 mm), and larger (16 mm) sized species, a similar pattern as for termite prey. Individual pangolin has fed largely on 14 ant species including *Crematogaster acis*, *Pheidole minima*, *Crematogaster (Oxygyne)* sp.2, *Anoploepis tenella*, *Anoplolepis carinata*, *Crematogaster (Oxygyne)* sp.1, *Crematogaster* sp.2, *Crematogaster (Decacrema)* sp.1, *Pheidole megacephala, Pheidole* sp.1, *Pheidole* sp.2, *Pheidole* sp.3, *Pheidole albidula*, *Pheidole. Minima* (smaller ants that may be eaten due to their high abundance and ease of harvesting perhaps) and other 11 larger-sized ants *Camponotus* sp.2, *Camponotus* sp.1 *Camponotus maculatus*, *Camponotus brutus*, *Camponotus pompeius Camponotus flavomarginatus, Camponotus chrysurus, Polyrachis decemdetata*, *Leptogenus vindicis*, *Hypoponera cognata*, and *Dorylus braunsi* which might be easy to harvest. This number of favorite preys is higher than that of Swart (1996) who recorded six ant species constituted 97% of the diet of the temminck's pangolin. *Anoplolepis custodiens* constituted the major prey (77% occurrence) while forming only 5% of the trapped ants (Swart, 1996). Pietersen *et al.* (2016) found the temminck's pangolin consuming four ant species different from the prey recorded in this study, but the same genus including, *Anoplolepis steingroeveri*, *Camponotus fulvopilosus*, two *Crematogaster* spp. Which represent 75% of the available ant species. These results support previous findings that pangolins have further specialized within an already unusual mammalian dietary niche. Our result is different from that obtained for the giant pangolin which prefers large ant species (see the section on Giant pangolin diet composition below). Some insect prey eaten by the white-bellied pangolin might be more likely to be selected than other prey according to their ecology as suggested by some authors working on the Temminck pangolin (see Swart *et al.*, 1999) or aardvark (Lindsey, 1999).

III.2.4.2 *Smutsia gigantea* diet composition

This survey shows that the giant pangolin fecal sample yielded a low proportion of ant and termite body parts in comparison to the examined stomach content and very few numbers of individuals undigested. The difference might be due to the level of digestion examined and the digestibility process which is complete in the gut and partial in the stomach. Our result is similar to previous authors' findings Mohamood *et al.* (2015); Ashokkumar *et al.* (2017) and Karawita *et al.* (2020). Likewise, these authors also recorded a higher proportion of clay and sands, similar to that from our survey where termite mounds, stones, and sands were 51.86% of total weight. In the fecal content analysis of Indian pangolins occurring in Pakistan, Mahmood *et al.* (2015) recorded these items account for more than 70% of the volume of the fecal samples analyzed. The plant matter low proportion obtained was similar to that of white-bellied pangolin stomach content which with other invertebrates recorded are considered as accidentally ingested as suggested by Karawita *et al.* (2020). Being considered as unintentional ingestion with the main prey items as recorded in low proportion, the plant material found in relatively high proportion in the Indian pangolin in Pakistan (Karawita *et al.*, 2020) is suggested to be included as a supplementary (Cabana *et al.*, 2017) in the food as it is an important source of fiber (Van Soest, 1994). The plant matter also reduces the damage on the walls of the stomach from the gastric juices by increasing the bulk to be digested (Pietersen *et al*., 2016)

Although based on initial and limited data, our survey confirms that giant pangolins eat ants and suggests they prefer relatively large ants (>15 mm length) and, in general, feed less on small species despite their greater abundance. The two giant pangolins sampled fed on eight to nine ant species, respectively, with eleven ant species in total in their collective samples. Pietersen *et al.* (2016) recorded five species in Temminck's pangolin diet. Fifteen ant species were recorded by Swart *et al.* (1999) for Temminck's pangolin. *Camponotus brutus* and *P. tarsatus* were the most abundant ant species in the juvenile giant pangolin's stomach, while *P. militaris* and *Ca. brutus* predominated in the adult pangolin's scat. This difference may simply reflect their latest feeding events. *Palthothyreus* recorded in this survey were mentioned by Kingdon & Hoffmann (2013).as part of the giant pangolins diet while other genera recorded here are not previously recorded. Variations in individual preferences and spatial and seasonal availability of prey may account, in part, for differences in prey species observed among studies (Swart *et al*., 1999). However more samples are needed; except for Mahamood *et al*. (2013), few authors have collected a large number of scats, because scats of the pangolins are scarce and rarely observed when some species hide their scat with soil (Kariwata *et al*., 2020).

The primary ant prey species of the giant pangolins, namely *Ca. brutus* (within the stomach of the juvenile pangolin) and *P. militaris* (within the scat of the adult pangolin), constituted <1% of the overall species composition (that is the number of species recorded in cursorial ant surveys) of the surveyed area, although making up 35% and 60% of ants consumed, respectively. This suggests that the giant pangolins preferentially feed on certain prey rather than feeding on the most abundant ant species. Similar behavior is reported for Temmincks' pangolin (Swart *et al.*, 1999; Pietersen *et al*., 2016) which favours *Anoplolepis custodiens* (Smith, 1858).

Differences in the composition of the fecal and stomach content samples may simply reflect each pangolin's latest feeding event, rather than individual or age-related preferences. Larger ants appear to be preferred by giant pangolins, which may increase their foraging efficiency, in terms of time, energy, and nutrient value quantity/mg (Swart *et al*., 1999). The nutritional value of ants increases with larger body size, greater population density, and larger nest structure (Swart *et al*., 1999). We examined an adult pangolin's scat and stomach contents from a juvenile pangolin. It remains uncertain if juvenile giant pangolins forage in the same ways as the adults as has been observed in the Temmincks' pangolin diet (Pietersen *et al*., 2016).

The surveyed giant pangolin individuals consumed larger termite species (>10 mm in length) and, in general, do not feed much on smaller termites despite their greater abundance.

Among the 53 termite species recorded in MDNP, four and six termite species were identified in the scat and stomach contents, respectively. The termite species found in both stomach and scat samples are different from those found in previous studies. Which focused on African pangolin species (Swart *et al*., 1999; Pietersen *et al.*, 2016). Among the prey species recorded and being eaten by giant pangolins here, the genera *Macrotermes, Pseudacanthotermes*, and *Isognathotermes* were previously mentioned by Kingdon & Hoffmann (2013) and Nixon *et al.* (2019). Termites represent less than 30% of the examined giant pangolin diets while ants were up to 80% of the insects recorded. Pangolins may favor ants over termites (Pietersen *et al.*, 2016; Swart *et al*., 1999; Coulson, 1989). However, it remains unknown if termites are eaten by giant pangolins for supplemental nutrients or for an antidiarrheal role as suggested for other mammal species (Deblauwe, 2009).

Giant pangolin prey selectivity

Cataulacus wessi and *Camponotus brutus* selection likelihood were the highest among all the prey. This suggests that giant pangolins may target larger-sized ants and termites. *Pseudacanthotermes militaris,* the most abundant termite species in both scat and stomach samples, has a similarly larger body size as the termite species recorded by Swart *et al*. (1999) and are larger than the species recorded by Pietersen *et al.* (2016) for the Temminck's pangolin. Like larger ants, giant pangolins may favor eating larger termite species for increased foraging efficiency (Swart *et al*., 1999).

III.2.5 Comparison of Ecological Knowledge

Local people were familiar with diet composition and other aspects of pangolins' ecology. Most respondents knew that pangolins feed predominantly on ants and termites and never on herbs and leaves. In field ecological study, similar composition in stomach and scat contents as those of local people were also recorded. The communities also reported specific locations in both forest and savanna where pangolins are usually found. These locations were successfully targeted with camera-traps and provided improvement on placement types such as fallen dead logs significantly more effective in WBP detection (Simo *et al*., 2020). Likewise, local people mostly mentioned GP occurring in savanna burrows which have provided more detection of GP than other habitat types. This LEK-based approach has enabled us to collect data on the ecology of pangolins as known by local people which matches well pangolin ecology from field ecological works.

Conclusion, Recommendations, and Perspectives

Conclusion

The present study aimed to assess habitat and food preferences and document the feeding behavior and ethno-zoological aspects of giant pangolin, white-bellied pangolin, and black-bellied pangolin in the savanna-forest ecotone in two national parks in central and eastern Cameroon.
Local communities around Mpem et Djim and Deng Deng national parks have a good ecological knowledge of pangolins and their knowledge reasonably correspond with what is observed in habitat and food preferences from ecological studies. Giant pangolin and white-bellied pangolin are well-known by local people who specify their specific sighting locations in both forest and savanna. However, black-bellied pangolin is poorly known and most often grouped with white-bellied pangolin verbally by local people as *petit pangolin* in French in these study areas. However, the two species are distinct morphologically, and local beliefs differ about the two species. Respondents reported that giant pangolins are commonly found in savanna burrows, while the white-bellied pangolins are often seen in the forest, crossing logs, and on trees. The black-bellied pangolins are reportedly sight by local people on rattan palms (*Raphia* spp.) in both forest and swampy habitats. Local people report ants and termites as the main preys of pangolins. From Local Ecological Knowledge surveys, this study shows that working with local communities can provide useful information for pangolin conservation and management efforts within protected areas. Local people know the ecology of pangolins and their knowledge reasonably not only correspond with observations from ecological field studies and have largely contributed to successfully planned ecological surveys through camera traps.

Overall, seven major vegetation types are present in both protected areas including savanna, saltwork, woodland savanna, grassland savanna, swamp, forest gallery, secondary forest, and near the primary forest. From the large camera-trap sampling efforts accumulated in both national parks studied, white-bellied pangolins are found in six different habitat types, including GS, GF, WS, SF, NPF, and SW and giant pangolins are frequent in savanna habitats, including GS, GF, and WS and in forest habitat namely SF. This research demonstrates that seasonal variation does not significantly affect the GP trapping rate. However, some habitat types record high trapping rates during the rainy season, particularly in gallery forests, grassland savanna, and woodland savanna. Near primary forest in DDNP and secondary forest in MDNP record a significantly higher trapping rate than in other habitat types of both parks. Some habitat types, placement targets and behavioral activities can predict detections.

Giant pangolin and white-bellied pangolin have similar feeding behavior in the different types of habitats and seasons in Deng Deng and Mpem et Djim national parks. Based on initial characterization of individual activities, giant pangolins' feeding behavior frequently includes individuals passing near the targets and foraging while eating activity might be rare. Likewise, giant pangolin individuals are rarely observed entering or/and exiting, or inspecting a burrow on field. Moreover, evidence of GP individual feeding is rarely observed in its habitat. White-bellied pangolins frequently exhibiting feeding behavior through eating, foraging, or passing and more rarely territorial behavior with individuals often entering or exiting the burrow, nesting, and scent marking its territory. In DDNP, gallery forest was used almost proportionally to its availability by GP and with three times the probability of its selection in MDNP and other habitat types. In both parks, almost all the habitat types were negatively selected by WBP. However, in MDNP, the probability to record WBP in SW and NPF were higher than in other habitat types.

Potential ant and termite preys of pangolins are present in both parks and their community compositions in the different habitat types by seasons are speciose richest, harboring up to 107 species, comprising 29 genera, and seven subfamilies. Formicinae dominate the other subfamilies followed by Myrmicinae in MDNP which is the most speciose subfamily in DDNP. Similarly, termites are also rich and diversify in both parks with 89 species comprising 33 genera, and nine subfamilies. Termitidae are the most speciose family compared to Rhinotermitidae. Macrotermitinae was represented by 29 species in DDNP and 28 species in MDNP. This was the most common subfamily in both protected areas followed by Cubitermitinae and then Nasutermitinae. Myrmecofauna and termitofauna of both parks are speciose rich and diversified respectively with significant more species in DDNP than MDNP. Habitat types significantly affect ant and termite species richness with the highest percentage recorded in mature forest habitats and lower in flooded habitats. Our initial characterization of the understory and ground ant and termite fauna of forest-savanna mosaic habitats of MDNP and DDNP, especially for the larger species, provides a foundation for evaluating prey preferences of pangolin species that occur in these forest-savanna mosaics.

In this study, giant pangolin, and white-bellied pangolin display different diet compositions, prey preferences and patterns in prey selection. The diets of 13 white-bellied pangolins include 144 species and morphospecies of insects comprising 39 termite species and 105 ant species. Ants were more abundant comprising 60.34% of the insects inventoried and speciose rich (105 species and 23 genera (92.0% of sampled genera). One scat and one stomach content examined reveal that giant pangolin feed on 70.1% of ants and 30% of termites. The termites recorded in the five stomach contents are less abundant (39.95% of the insects recorded). Seasonal variation significantly affects the mean abundance of ants and termites eaten by WBP. This study has shown that WBP fed on, and positively selected termite prey species and more ants among the sampled prey. Our result suggests that a large number of ants and termites were eaten by WBP. White-bellied pangolin feed preferentially on 4 termite prey species, and positively select *Macrotermes bellucosus*. While 10 ant species were preferentially eaten, with positively selected preys including *Crematogaster acis* and *Crematogaster* (*Oxygyne*) sp.2. The dry season might be more favorable to increase food harvesting especially ant species and the rainy season more favorable for termite harvesting. For more effectiveness in practice, the time budget spends to collect enough prey items should be evaluated according to the age and sex of pangolins. *Nasutitermes arborum* and *Crematogaster acis* were amongst the most important termite and ant food sources respectively.

The two giant pangolins sampled fed on eight to nine ant species, respectively, with eleven ant species in total in their collective samples. The giant pangolin fecal sample yielded a low proportion of ant and termite body parts in comparison to the examined stomach content and very few numbers of individuals undigested. Although based on initial and limited data, our survey confirms that giant pangolins eat ants and suggests they prefer relatively large ants and, in general, feed less on small species despite their greater abundance. *Camponotus brutus* and *Palthothyreus tarsatus* were the most abundant ant species in the juvenile giant pangolin's stomach, while *Polyrachis militaris* and *Ca. brutus* predominated in the adult pangolin's scat. Giant pangolin consumed larger termite species and, in general, do not feed much on smaller termites despite their greater abundance. Four and six termite species were identified in the scat and stomach contents, respectively. This study provides baseline information on the giant pangolin and white-bellied pangolin diets in Cameroon. It gives a large range of pangolin prey and preferential eaten species especially for white-bellied pangolin which can be used to better plan conservation actions through rehabilitation and release of rescued pangolin individuals. This could be done by selecting ant and termite prey species microhabitats on the ground or tree in a forest or savanna to help make pangolin forage and feed during rehabilitation.

Recommendations

To implement the results of this work to protect these endangered species and to continue benefiting from their ecosystem services. It is recommended to:

- the authorities in charge of forest and wildlife conservation

  (1) to engage in capacity building and awareness raising among wildlife managers and local communities;

  (2) to evaluate the effectiveness of such efforts and ideally, work in collaboration with local communities for effective results;

  (3) to reduce poaching pressure, explore feasibility and development of (a) equitable and sustainable management of hunting, and (b) sustainable farming as an alternative source of protein, income, and employment for local people;

  (4) to strengthen conservation measures for forest and savanna habitats especially gallery forest, near primary forest, secondary forest and swamp in MDNP and DDNP and surroundings. Of course, habitat protection is only part of the solution, as there must be effective crime prevention against wildlife and law enforcement;

- Researchers and NGOs
  - (5) future research efforts should focus on identifying suitable methods to accurately detect the presence and abundance of black-bellied pangolin and other pangolin species;
  - (6) strengthen ecological research efforts in gallery forest and grassland savanna for giant pangolin and in swamp habitat for white-bellied pangolin;
  - (7) reintroduction practitioners should select ant and termite prey species microhabitats on the ground or trees in forest or savanna to encourage pangolin foraging and feeding;
  - (8) harvest sufficient amount of preferential and highly selected ant and termite preys to provide food to pangolin individuals in rehabilitation and reintroduction center;
  - (9) Reintroduce pangolin individual rehabilitated in the main habitat use by pangolin according to species;
  - (10) Improve focused pangolin camera-trapping and detection rates through targeting of foraging and eating microsites with high pangolin activities such as fallen logs and termite mounds.

Perspectives

To improve our knowledge of pangolin and enhancing conservation actions in our future work, we plan to develop other aspects such as:

- carrying out more ant and termite sampling using more diverse methods (for example, Winkler litter-sifting, nocturnal baiting, soil sampling, canopy sampling), and a standardized sampling technique for termites (Jones & Eggleton, 2000) undertaken in different seasons to fully characterize the ant and termite fauna of this forest-savanna ecotone;
- assessing ecology traits of pangolin insect prey (e.g., their dominance in habitat, nesting site (ground or tree-canopy ant), mechanism of defense and nest construction) to better understand the feeding ecology of pangolins;
- further investigations are required to assess variations of white-bellied pangolin and giant pangolin preys according to sex, body size, and age of the individual;
- assessing more samples of white-bellied pangolin and giant pangolin scat and stomach contents for full characterization of these species' diets;
- carrying out Laboratory tests of the food preference and isotopes analysis of pangolins species to fully examine prey preference in the situation of equal quantity of prey available and evolution of diets across life stage;
- evaluate the biochemical composition and nutritional value of pangolin prey insects to investigate the possibility of food substitutes with artificial diets for ex-situ conservation and reintroduction program;
- explore the feasibility of captive breeding to increase pangolin numbers and also how to use *ex-situ* populations to re-establish wild populations;
- explore the feasibility of using canopy arboreal and log-based placement strategies to monitor black-bellied pangolins;
- explore more factors defining habitat preference of each pangolin species to better characterize habitat usage;
- evaluate reproductive patterns of pangolin species to enhance success in capture-rearing and farming.

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Appendices

Appendix 1: semi-structured questionnaire (French Version) used during the community survey

REPUBLIQUE DU CAMEROUN
Paix-Travail-Patrie
UNIVERSITE DE YAOUNDE I
FACULTE DES SCIENCES
BP: 337 Yaoundé

REPUBLIC OF CAMEROON
Peace-Work-Fatherland
UNIVERSITY OF YAOUNDE I
FACULTY OF SCIENCE
P.O. 337 Yaoundé

DEPARTEMENT DE BIOLOGIE ET PHYSIOLOGIE

Questionnaire pour l'étude des communautés locales

Nous sommes des étudiants de l'Université de Yaoundé I. Nous voulons en savoir plus sur la perception des populations locales sur la biologie et la conservation des Pangolins. Nous collectons des données pour nos travaux de Doctorat/PhD et nous travaillons dans l'esprit de la loi N° 91/023 du 16 décembre 1991 sur les recensements et enquêtes statistiques au Cameroun qui stipule en son article 5 que les renseignements individuels, d'ordre économiques, financier ou sociaux figurant sur tout questionnaire d'enquête statistique ne peuvent en aucun cas être utilisés à des fins de contrôle ou de répression. Soyez donc rassurés, les fiches sont anonymes et toute vos réponses classées confidentielles.

Fiche N° ☐

Date	**Localité**
Ville	**Village**

I. Identification du répondant:

A. Sexe :

1. Masculin ☐

B. Age :

1. Moins de 15 ans ☐
2. [15 à 25 ans [☐
3. [25 à 35 ans [☐
4. [35 à 45 ans [☐
5. [35 à 45 ans [☐
6. 55 ans et plus ☐

C. Niveau Scolaire:

1. Aucun ☐
2. Maternel ☐
3. Primaire ☐
4. Secondaire ☐
5. Supérieur ☐

D.Religion:

1. Musulman ☐
2. Chrétien ☐
3. Autres (à spécifier)……………………………

E. Ethnie…………………………………………

F. Occupation principale:

1. Chasseur ☐
2. Agriculteur ☐
3. Commerçant ☐
4. Pécheur
☐. Autres (à spécifier)

II. Connaissance des animaux étudiés

1) (Photo de l'ourse) Connaissez-vous cet animal ? 1. Oui ☐ 0. Non☐
Pouvez-vous nommez cet animal ____1. Vrai Nom ☐ 0. Faux Nom☐

2) l'avez-vous déjà vu dans l'environnement ? 1. Oui ☐ 0. Non☐

3) Où avez-vous souvent vu cet animal ? 1. En forêt ☐ 2. Sur le marché☐ 3. Au village ☐ 4. Autres (à spécifier)…………………………………………………………

4) Quand l'avez-vous vu pour la dernière foi ? 1. 2018☐ 2. 2017 ☐ 3. 2016 ☐ 4. Avant 2016
5) Pensez-vous qu'actuellement le nombre de cet animal est : 1. Réduit 2. Stable ☐ 3. Elevé☐

6) (Photo du Chat doré africain) Connaissez-vous cet animal ? 1. Oui ☐ 0. Non☐

Pouvez-vous nommez cet animal ____1. Vrai Nom ☐ 0. Faux Nom☐

7) l'avez-vous déjà vu dans l'environnement ? 1. Oui ☐ 0. Non☐

8) Où avez-vous souvent vu cet animal ? 1. En forêt ☐ 2. Sur le marché☐ 3. Au village ☐
4. Autres (à spécifier)……………………………………………………

9) Quand l'avez-vous vu pour la dernière foi ? 1. 2018☐ 2. 2017 ☐ 3. 2016 ☐ 4. Avant 2016

10) Pensez-vous qu'actuellement le nombre de cet animal est : 1. Réduit 2. Stable ☐ 3. Elevé☐

11) (Photo du Pangolin géant) Connaissez-vous cet animal ? 1. Oui ☐ 0. Non☐

Pouvez-vous nommez cet animal ____1. Vrai Nom ☐ 0. Faux Nom☐

12) l'avez-vous déjà vu dans l'environnement ? 1. Oui ☐ 0. Non☐

13) Où avez-vous souvent vu cet animal ? 1. En forêt ☐ 2. Sur le marché☐ 3. Au village ☐
4. Autres (à spécifier)……………………………………………………

14) Quand l'avez-vous vu pour la dernière foi ? 1. 2018☐ 2. 2017 ☐ 3. 2016 ☐ 4. Avant 2016

15) Pensez-vous qu'actuellement le nombre de cet animal est : 1. Réduit 2. Stable ☐ 3. Elevé☐

16) (Photo du Pangolin à ventre blanc) Connaissez-vous cet animal ? 1. Oui ☐ 0. Non☐

Pouvez-vous nommez cet animal ____1. Vrai Nom ☐ 0. Faux Nom☐

17) l'avez-vous déjà vu dans l'environnement ? 1. Oui ☐ 0. Non☐

18) Où avez-vous souvent vu cet animal ? 1. En forêt ☐ 2. Sur le marché☐ 3. Au village ☐
4. Autres (à spécifier)……………………………………………………

19) Quand l'avez-vous vu pour la dernière foi ? 1. 2018☐ 2. 2017 ☐ 3. 2016 ☐ 4. Avant 2016

20) Pensez-vous qu'actuellement le nombre de cet animal est : 1. Réduit 2. Stable ☐ 3. Elevé☐

21) (Photo du Pangolin à ventre noir) Connaissez-vous cet animal ? 1. Oui ☐ 0. Non☐

Pouvez-vous nommez cet animal ____1. Vrai Nom ☐ 0. Faux Nom☐

22) l'avez-vous déjà vu dans l'environnement ? 1. Oui ☐ 0. Non☐

23) Où avez-vous souvent vu cet animal ? 1. En forêt ☐ 2. Sur le marché☐ 3. Au village ☐
4. Autres (à spécifier)……………………………………………………

24) Quand l'avez-vous vu pour la dernière foi ? 1. 2018☐ 2. 2017 ☐ 3. 2016 ☐ 4. Avant 2016

25) Pensez-vous qu'actuellement le nombre de cet animal est : 1. Réduit 2. Stable ☐ 3. Elevé☐

III. Connaissances de l'écologie traditionnelle

1) **Où trouve-t-on généralement les pangolins ?1**. Au champ ☐**2**. En forêt ☐**3**. En route ☐**4.** Près des maisons ☐

Si **2** Où les trouve-t-on en forêt ?**1**. Les terriers ☐**2**. Sur les arbres ☐**3**. Près des rivières ☐**5.** Autres (à 280pecifier)……………………………………………………………

2) Y a-t-il des terriers dans la région 1. Oui ☐ 0. Non☐

3) **A quel moment trouve-t-on les pangolins ? 1**. En journée ☐**2**. La nuit ☐**3**. Je ne sais pas ☐**4.** Autre…………………………………..

4) **Avez-vous déjà trouvé deux pangolin sensemble ? 1.** Oui ☐**0.** Non ☐

Si Oui. **1**. Deux adultes ☐**2**. Un adulte et un jeune ☐**3**. Deux jeunes ☐**4.** Autres (à 281pecifier)……………………………………………………………….……

5) **Avez-vous déjà vu les pangolins en train de s'accoupler ?1.** Oui ☐**0.** Non ☐

Si oui. Pouvez-vous nous dire comment ils procèdent ?... ?..
....
....

6) **A quelle fréquence mettent-ils bas : 1**. Mensuellement ☐**2**. Annuellement ☐**3**. Deux fois par moi **4.** Je ne sais pas ☐

7) **Combien de petit par mise bas :1**. Un ☐**2**. Deux ☐**3**. Trois ☐**4.** Je ne sais pas ☐ Autres……………….

8) **De quoi se nourrissent-ils ?1**. Fourmi ☐**2**. Termites ☐**3**. Feuilles d'arbres☐**4.** Herbes ☐ 5.Autres spécifier)……………………………

Si **1 de quelles fourmis se nourrissent-ils ? 1**. Fourmis rouge ☐ **2**. Fourmis noire ☐ **3.** Autres

Appendix 2: Supplementary material: simplified sheet of pre-established conventional code of vegetation and habitat physiognomic characterization for wildlife inventory (ZSL, 2017 modified).

Vegetation (detailed for transects)	**codes**	**Habitat closure categories**	**Codes**
Bai (Marshy clearing)	B	Very opened understory habitat (≥15m)	VO
Forest-Marantaceae	FM	Open understory habitat (15m)	O
Forest-seasonally inundated	FI	closed understory habitat (10m)	C
Forest-Monodominant	Fmomo	Very-closed understory habitat (≤5m)	VC
Secondary Forest	FS		
Near primary forest	NPF	**Category of canopy closure**	
Inselberg	INS	Very opened canopy habitat (≥25%)	VO
Swamp	SW	Open canopy habitat (50%)	O
Grassland Savanna	GS	closed canopy habitat (75%)	C
Woodland Savanna	WS	Very-closed canopy habitat (100%)	VC
Gallery Forest	GF		
Plantation	PLT	**Slope categories**	
Raphia Swamp	RAP	Flat	0
River	Riv	Moderate	1
Rock	Roc	Steep	2
Salt lick / Saltworks	SL		
Gap in canopy (tree fall)	TR		
Undergrowth type	**Codes**	**Visibility in undergrowth**	**Codes**
Herbs	H	Very open (more than 15 m)	VO
Saplings/bushy	S	Open (10-15 m)	O
Lianas	L	Closed (5-10 m)	C
Grass	G	Very closed (<5m)	VC
None	N		

Appendix 3 : Photos of different animal used during the questionnaire survey

Figure 66: Animal species photos used for respondent response accuracy ckeck test during the questionnaire survey: A) *Smutsia gigantea* (Giant pangolin); B) *Phataginus tricuspis* (White-bellied pangolin); C) *Phataginus tetreadactyla* (Black-bellied pangolin)*;* D) *Caracal aurata (*Caracal*);* E) *Ursus arctos (*Brown bear)

Appendix 4: the main used camera traps mark and model setting adapted according to protocol from ZSL 2017 field survey

Bushnell Essential E Brown 119837, Bushnell Trophy Cam HD 119873, Bushnell Trophy Camera Brown 119836. MODE OPTIONS following ZSL protocol November 2015. Other marks include Cuddeback Xchange Color 1279, Cuddeback IR E2, Moltrie 30i

Parameters	**From 2018 to 2020**	**Effect and Reasons**
Mode	Camera	Takes still photos not video
Image size	8M	Compromise between image quality and disc space
Image format	Wide Screen	More pictures
Capture number	3 photos	
LED Control	High (Medium for first 15 cameras)	Note ‘Medium’ setting locks NV shutter to high.
Camera name	Enter C01, C02.etc.	
Video size	Not applicable (1280x720)	
Video length	Not applicable (10s)	
Interval	2 second	Matches Reconyx camera ‘No delay’ setting while noting Bushnell recommendation that setting this to1 second uses batteries fast.
Sensor level	Normal	Appropriate for warm conditions

NV shutter	Medium	Locked at High for first 15 cameras because LED control set to Medium.
Camera mode	24hrs.	
Format	[Never press ‘OK’ on a recovered camera until you know the data card has been downloaded and backed up!!]	Erases everything on card, To avoid this press ‘Menu’ or press ‘No – then OK’
Time stamp	On [set to off for first 15]	Prints date and time on every photo
Set clock	Set	Use manual instructions to set correct time and date
Field scan	Off – No time lapse images	
Coordinate input	Off	Use manual instructions to enter coordinate
Video sound	Off	
Default set	Cancel	

Appendix 5: Some material used for ecological field work

Bushnell camera traps

Sleeping mat

GPS GARMIN 64S

SUHUNTO compass

Headtorch

AA Energizer batteries

AAA Energizer batteries

Figure 67: Some material used for ecological field work

Appendix 6: number of camera trap stations surveyed in each habitat during the survey period

Habitat types	**DDNP**	**MDNP**	**Total**
Gallery Forest	2 (1.64%)	3 (2.46%)	5 (4.10%)
Grassland savanna	12 (9.84%)	8 (6.56%)5	20 (16.39%)
Near Primary Forest	10 (8.20%)	1 (19.02%)	21 (17.21%)
Secondary Forest	12 (9.84%)	30 (24.59%)	42 (34.43%)
Swamp	8 (6.54%)	1 (0.82%)	9 (7.38%)
Woodland savanna	14 (11.48%)	9 (7.38%)	23 (18.85%)
Total	**58 (47.54%)**	**64 (**52.46%)	**122 (**100.00)

Appendix 7: Number of Camera trap stations surveyed per model and mean of sampling effort

Camera trap models	**Number of installed camera**	**Cumulative sampling effort**	**Means**	**Max**	**Min**
Bushnell Essential E Brown 119837	11	935	85	99	7
Bushnell Trophy Camera Brown 119836	50	4146	82.92	112	1
Busnell Trophy Cam HD 119873	10	824	82.4	108	25
Busnell Trophy Cam HD 119874	2	188	94	95	93
Busnell Trophy Cam HD 119875	2	188	94	94	94
Cuddeback IR E2	20	1526	76.3	107	27
Cuddeback Xchange Color 1279	19	1339	70.47	112	2
Cuddeback Xchange Color 1280	7	489	69.85	107	24
Cuddeback Xchange Color 1281	2	207	103.5	111	96
Cuddeback Xchange Color 1282	2	117	58.5	63	54
Cuddeback Xchange Color 1283	1	99	99	99	99
Moltrie 30i	10	829	82.9	111	21
Total	136	**10887**	**80,05**		

Max= Maximum, Min= Minimum

Appendix 8 : cumulative Sampling effort per park and habitat type

Habitat types	**DDNP**	**MDNP**	**Total**
Gallery Forest	207	193	400
Grassland savanna	1052	615	1667
Near Primary Forest	603	930	1533
Secondary Forest	873	4123	4996
Swamp	522	95	617
Woodland savanna	927	747	1674
Total	**4184**	**6703**	**10887**

Appendix 9: Cumulative number of giant pangolin photos per park and habitat type

Habitat types	**DDNP**	**MDNP**	**Total**
Gallery forest	7	8	15
Grassland savanna	6	38	44
Near primary forest	0	0	0
Secondary forest	2	20	22
Swamp	0	0	0
Woodland savanna	15	30	45
Total	**30**	**96**	**126**

Appendix 10:Cumulative white-bellied pangolin number of photos per park and habitat type

Habitat types	DDNP	MDNP	**Total**
Gallery forest	0	3	**3**
Grassland savanna	3	0	**3**
Near primary forest	248	96	**344**
Secondary forest	119	1103	**1222**
Swamp	15	3	**18**
Saltworks	0	0	**0**
Woodland savanna	37	10	**47**
Total	422	1215	**1637**

Appendix 11: Actual and relative abundance/importance of ant species eaten by white-bellied pangolin individuals in this study

	WBP01	WBP02	WBP03	WBP04	WBP05	WBP06	WBP07	WBP08	WBP09	WBP10	WBP11	WBP12	WBP13	**Ar**	**Fo**	RI	Cat
Formicidae	**85.06 (27955)**	**83.38 (10496)**	**64.72 (3038)**	**13.62 (2248)**	**47.2 (4003)**	**38.49 (3341)**	**76.03 (13022)**	**59.92 (21066)**	**37.62 (3164)**	**78.03 (6905)**	**51.22 (989)**	**31.67 (2790)**	**59.38 (633)**	**60.34 (99650)**	100	60.34	C
Dolichoderinae	**0.15 (48)**	**0 (0)**	**3.92 (184)**	**0.02 (3)**	**0.88 (75)**	**0.02 (2)**	**1.75 (300)**	**1.95 (684)**	**0.64 (54)**	**0.01 (1)**	**0 (0)**	**0.76 (67)**	**0.56 (6)**	**0.86 (1424)**	**84.62**	0.73	C
Axinidris	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.88 (75)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0.56 (47)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.07 (123)**	**23.08**	0.02	**Acl**
Axinidris bidens	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Axinidris sp.1	0 (0)	0 (0)	0 (0)	0 (0)	0.88 (75)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (75)	7.69	0	Acl
Axinidris sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.56 (47)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (47)	7.69	0	Acl
Tapinoma	**0.01 (3)**	**0 (0)**	**0.09 (4)**	**0.01 (2)**	**0 (0)**	**0.01 (1)**	**0 (0)**	**1.35 (476)**	**0 (0)**	**0.01 (1)**	**0 (0)**	**0.76 (67)**	**0 (0)**	**0.34 (554)**	**53.85**	0.18	**A**
Tapinoma melanocephalum	0.01 (3)	0 (0)	0.09 (4)	0.01 (2)	0 (0)	0.01 (1)	0 (0)	1.11 (392)	0 (0)	0 (0)	0 (0)	0.76 (67)	0 (0)	0.28 (469)	46.15	0.13	**A**
Tapinoma sp.1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Tapinoma sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.24 (84)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (84)	7.69	0	Acl
Technomyrmex	**0.14 (45)**	**0 (0)**	**3.83 (180)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**1.75 (300)**	**0.59 (208)**	**0.08 (7)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.56 (6)**	**0.45 (747)**	**53.85**	0.24	**C**
Technomymex sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.89 (152)	0.14 (50)	0.08 (7)	0 (0)	0 (0)	0 (0)	0.56 (6)	0.13 (215)	30.77	0.04	**Acl**
Technomymex sp.3	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0.86 (147)	0.45 (158)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.19 (306)	23.08	0.04	Acl
Technomyrmex sp.1	0.14 (45)	0 (0)	3.83 (180)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.14 (226)	23.08	0.03	Acl
Dorylinae	**0.01 (3)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.04 (7)**	**0 (0)**	**0.42 (35)**	**0.12 (11)**	**0.73 (14)**	**1.02 (90)**	**0.19 (2)**	**0.1 (162)**	53.85	0.05	Acl
Dorylus	**0.01 (3)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.04 (7)**	**0 (0)**	**0.42 (35)**	**0.12 (11)**	**0.73 (14)**	**1.02 (90)**	**0.19 (2)**	**0.1 (162)**	**53.85**	0.05	**A**
Dorylus braunsi	0.01 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (3)	7.69	0	Acl
Dorylus nigricans	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (10)	0.73 (14)	1.02 (90)	0.19 (2)	0.07 (116)	30.77	0.02	**Acl**
Dorylus sp.1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (1)	7.7	0	Acl
Dorylus sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.42 (35)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (35)	7.69	0	Acl
Dorylus striatidiens	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.04 (6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (6)	7.69	0	Acl
Formicidae sbfam 1	**5.29 (1740)**	**0.32 (40)**	**0 (0)**	**0.38 (63)**	**2 (170)**	**0 (0)**	**0 (0)**	**0 (0)**	**19.02 (1600)**	**3.86 (342)**	**13.36 (258)**	**7.58 (668)**	**2.81 (30)**	**2.97 (4911)**	**69.23**	**2.06**	**C**
Formicidae gen 1	5.29 (1740)	0.32 (40)	0 (0)	0.38 (63)	2 (170)	0 (0)	0 (0)	0 (0)	4.76 (400)	3.39 (300)	13.36 (258)	7.58 (668)	2.81 (30)	2.22 (3669)	69.23	1.54	C
Formicidae sp.1	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	14.27 (1200)	0.47 (42)	0 (0)	0 (0)	0 (0)	0.75 (1242)	15.38	0.12	Acl
Formicidae sbfam 2	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.11 (18)**	**23.98 (8432)**	**0.24 (20)**	**0.24 (21)**	**0 (0)**	**4.09 (360)**	**0 (0)**	**5.36 (8851)**	**38.46**	**2.06**	**C**

Formicidae gen 2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (18)	23.98 (8432)	0.24 (20)	0.24 (21)	0 (0)	4.09 (360)	0 (0)	5.36 (8851)	38.46	2.06	**C**
Formicidae sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (18)	23.98 (8432)	0.24 (20)	0.24 (21)	0 (0)	4.09 (360)	0 (0)	5.36 (8851)	38.46	2.06	**C**
Formicidae sbfam 3	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.09 (32)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.02 (32)**	**7.69**	**0**	**Acl**
Formicidae gen 3	*0 (0)*	*0 (0)*	*0 (0)*	*0 (0)*	*0 (0)*	*0 (0)*	*0 (0)*	*0.09 (32)*	*0 (0)*	*0 (0)*	*0 (0)*	*0 (0)*	*0 (0)*	*0.02 (32)*	*7.69*	*0*	*Acl*
Formicidae sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.09 (32)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (32)	7.69	0	Acl
Formicidae sbfam 4	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**1.19 (420)**	**0 (0)**	**5.09 (450)**	**15.02 (290)**	**0 (0)**	**28.14 (300)**	**0.88 (1460)**	**30.77**	**0.27**	**A**
Formicidae gen 4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.19 (420)	0 (0)	5.09 (450)	15.02 (290)	0 (0)	28.14 (300)	0.88 (1460)	30.77	0.27	**A**
Formicidae sp.4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.19 (420)	0 (0)	5.09 (450)	15.02 (290)	0 (0)	28.14 (300)	0.88 (1460)	30.77	0.27	**A**
Formicinae	**15.42 (5069)**	**25.54 (3215)**	**8.84 (415)**	**2.44 (402)**	**16.05 (1361)**	**1.59 (138)**	**58.07 (9945)**	**5.39 (1896)**	**6.87 (578)**	**67.09 (5937)**	**4.14 (80)**	**10.57 (931)**	**16.98 (181)**	**18.25 (30148)**	100	18.25	C
Anoplolepis	**4.2 (1380)**	**0.73 (92)**	**2.41 (113)**	**0.41 (68)**	**0 (0)**	**0 (0)**	**54.88 (9400)**	**2.88 (1014)**	**0 (0)**	**64.72 (5727)**	**2.28 (44)**	**4.71 (415)**	**11.91 (127)**	**11.13 (18380)**	**76.92**	8.56	**C**
Anoplolepis carinata	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	52.66 (9019)	0.85 (300)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5.64 (9319)	15.38	0.87	C
Anoplolepis tenella	4.2 (1380)	0.73 (92)	2.41 (113)	0.41 (68)	0 (0)	0 (0)	2.22 (381)	2.03 (714)	0 (0)	64.72 (5727)	2.28 (44)	4.71 (415)	11.91 (127)	**5.49 (9061)**	76.92	4.22	C
Camponotus	**10.29 (3381)**	**20.01 (2519)**	**3.13 (147)**	**0.88 (146)**	**15.78 (1338)**	**0.43 (37)**	**2.55 (436)**	**0.86 (303)**	**3.86 (325)**	**1.63 (144)**	**1.86 (36)**	**2.99 (263)**	**4.97 (53)**	**5.53 (9128)**	**100**	5.53	**C**
Camponotus (Paramymablys) sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.12 (10)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (10)	7.69	0	Acl
Camponotus (Tanaemyrmex) sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (2)	7.69	0	Acl
Camponotus acvapimensis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (10)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (10)	7.69	0	Acl
Camponotus brutus	0.01 (2)	0 (0)	0 (0)	0.01 (2)	0.07 (6)	0 (0)	0.74 (126)	0.09 (31)	0.7 (59)	0.31 (27)	0.05 (1)	1.65 (145)	2.72 (29)	0.26 (428)	76.92	0.2	A
Camponotus buchholzi	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (26)	0.05 (1)	0.47 (41)	1.88 (20)	0.05 (88)	30.77	0.02	**A**
Camponotus chapini	8.32 (2734)	12.97 (1633)	0.64 (30)	0.42 (69)	11.45 (971)	0.01 (1)	0.04 (6)	0.21 (75)	0.13 (11)	0 (0)	0 (0)	0.02 (2)	0 (0)	3.35 (5532)	76.92	2.58	C
Camponotus chrysurus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (4)	0 (0)	0 (0)	0 (0)	0 (4)	7.69	0	Acl
Camponotus flavomarginatus	1.3 (428)	6.2 (781)	0.43 (20)	0.33 (54)	4.14 (351)	0.3 (26)	0.23 (40)	0.02 (6)	0.1 (8)	0.19 (17)	0.16 (3)	0.01 (1)	0 (0)	1.05 (1735)	92.31	0.97	C
Camponotus maculatus	0.21 (68)	0.81 (102)	0.79 (37)	0.01 (2)	0 (0)	0.09 (8)	0.45 (77)	0 (0)	2.78 (234)	0.14 (12)	0 (0)	0 (0)	0.09 (1)	0.33 (541)	69.23	0.23	A
Camponotus pompeuis	0.1 (33)	0.02 (3)	1.28 (60)	0 (0)	0.12 (10)	0 (0)	0.41 (71)	0 (0)	0.04 (3)	0.27 (24)	0 (0)	0 (0)	0 (0)	0.12 (204)	53.85	0.07	A
Camponotus simus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (2)	0 (0)	0.37 (129)	0 (0)	0.05 (4)	0 (0)	0 (0)	0 (0)	0.08 (135)	23.08	0.02	Acl
Camponotus sp.1	0.35 (116)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.07 (116)	7.69	0.01	Acl
Camponotus sp.2	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0.18 (30)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (31)	15.38	0	Acl
Camponotus sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.18 (30)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (30)	7.69	0	Acl
Camponotus sp. 4*	0 (0)	0 (0)	0 (0)	0.11 (18)	0 (0)	0 (0)	0.32 (54)	0.15 (52)	0 (0)	0.34 (30)	1.61 (31)	0.84 (74)	0.28 (3)	0.16 (262)	53.85	0.09	A

Cataulacus	**0 (0)**	**0.87 (110)**	**0.02 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.07 (111)**	**15.38**	0.01	**Acl**
Cataulacus guineensis	0 (0)	0 (0)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Cataulacus tardus	0 (0)	0.87 (110)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.07 (110)	7.69	0.01	Acl
Lepisiota	**0.48 (159)**	**0 (0)**	**0 (0)**	**0.58 (96)**	**0 (0)**	**1.14 (99)**	**0 (0)**	**1.21 (424)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.47 (778)**	**30.77**	0.14	**A**
Lepisiota nigriventris	0.48 (159)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.1 (159)	7.69	0.01	Acl
Lepisiota oculata	0 (0)	0 (0)	0 (0)	0.58 (96)	0 (0)	1.14 (99)	0 (0)	1.21 (424)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.37 (619)	23.08	0.09	Acl
Polyrachis	**0.02 (8)**	**3.88 (489)**	**1.19 (56)**	**0.56 (92)**	**0.27 (23)**	**0.02 (2)**	**0.64 (109)**	**0.44 (154)**	**3.01 (253)**	**0.75 (66)**	**0 (0)**	**2.87 (253)**	**0.09 (1)**	**0.91 (1506)**	**92.31**	0.84	**C**
Polyrachis decemdetata	0 (0)	0.24 (30)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (12)	0.04 (3)	0.16 (14)	0 (0)	0.14 (12)	0.09 (1)	0.04 (72)	46.15	0.02	**A**
Polyrachis fissa	0 (0)	0 (0)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Polyrachis gagates	0 (0)	0.21 (26)	0 (0)	0.01 (2)	0 (0)	0 (0)	0 (0)	0.1 (36)	0.13 (11)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (75)	30.77	0.01	**A**
Polyrachis latispina	0.01 (3)	0 (0)	0.04 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (5)	15.38	0	Acl
Polyrachis militaris	0.02 (5)	3.44 (433)	1.13 (53)	0.37 (61)	0.27 (23)	0.02 (2)	0.49 (84)	0.14 (50)	2.84 (239)	0.59 (52)	0 (0)	2.74 (241)	0 (0)	0.75 (1243)	84.62	0.64	C
Polyrachis sp.1	0 (0)	0 (0)	0 (0)	0.18 (29)	0 (0)	0 (0)	0.15 (25)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (54)	15.38	0.01	Acl
Polyrachis sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.06 (22)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (22)	7.69	0	Acl
Polyrachis sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.1 (34)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (34)	7.69	0	Acl
Pseudolasius	0.43 (141)	0.04 (5)	2.09 (98)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.15 (244)	23.08	0.03	Acl
Pseudolasius weissi	0.43 (141)	0.04 (5)	2.09 (98)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.15 (244)	23.08	0.03	Acl
Tapinoleplis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Tapinoleplis sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Myrmicinae	**64.18 (21092)**	**57.48 (7235)**	**51.66 (2425)**	**10.43 (1721)**	**28.26 (2397)**	**36.88 (3201)**	**15.9 (2724)**	**27.3 (9599)**	**10.43 (877)**	**1.58 (140)**	**17.97 (347)**	**7.59 (669)**	**10.41 (111)**	**31.81 (52538)**	100	31.81	C
Cardiocondyla	0 (0)	0 (0)	0 (0)	1.45 (240)	0 (0)	0 (0)	0 (0)	1.65 (580)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.5 (820)	15.38	0.08	Acl
Cardiocondyla sp.	0 (0)	0 (0)	0 (0)	1.45 (240)	0 (0)	0 (0)	0 (0)	1.65 (580)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.5 (820)	15.38	0.08	Acl
Cataulacus	0 (0)	0.57 (72)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.04 (74)	23.08	0.01	Acl
Cataulacus guineensis	0 (0)	0.57 (72)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.04 (74)	23.08	0.01	Acl
Crematogaster	**34.99 (11498)**	**42.1 (5299)**	**37.26 (1749)**	**3.76 (620)**	**23.39 (1984)**	**35.52 (3083)**	**7.65 (1310)**	**4.61 (1622)**	**2.08 (175)**	0.84 (74)	**17.97 (347)**	**7.57 (667)**	**10.04 (107)**	**17.28 (28535)**	**100**	17.28	**C**
Crematogaster (*Crematogaster*) sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.55 (221)	0 (0)	0 (0)	0 (0)	0.29 (26)	0 (0)	0 (0)	0 (0)	0.15 (247)	15.38	0.02	Acl
Crematogaster (*Decacrema*) sp.1	0 (0)	0 (0)	0.83 (39)	0 (0)	0 (0)	0.26 (23)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.04 (62)	15.38	0.01	Acl
Crematogaster (*Decacrema*) sp.2	10.95 (3600)	0 (0)	0 (0)	0 (0)	0 (0)	1.44 (125)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.26 (3725)	15.38	0.35	Acl
Crematogaster (*Orthocrema*) sp.1	0 (0)	0 (0)	0 (0)	0 (0)	5.19 (440)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.27 (440)	7.69	0.02	Acl

Crematogaster (*Orthocrema*) sp.2	0 (0)	0 (0)	0 (0)	0 (0)	2.36 (200)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.12 (200)	7.69	0.01	Acl
Crematogaster (*Oxygyne*) sp.1	14.72 (4839)	0 (0)	0.62 (29)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.95 (4868)	15.38	0.45	A
Crematogaster (*Oxygyne*) sp.2	0 (0)	0 (0)	0.02 (1)	2.42 (400)	0 (0)	0 (0)	0 (00 (0))		0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.24 (401)	15.38	0.04	Acl
Crematogaster (*Oxygyne*) sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (1)	7.57 (667)	9.85 (105)	0.47 (773)	23.08	0.11	A
Crematogaster (*Sphaerocrema*) sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Crematogaster (*Sphaerorema*) sp.1	0 (0)	0 (0)	0 (0)	0 (0)	0.34 (29)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (30)	15.38	0	Acl
Crematogaster acis	0 (0)	29.41 (3702)	26.84 (1260)	0.88 (145)	4.75 (403)	3.93 (341)	3.4 (583)	4.27 (1502)	2.08 (175)	0.46 (41)	17.92 (346)	0 (0)	0.19 (2)	5.15 (8500)	84.62	4.35	C
Crematogaster concava	9.17 (3012)	0 (0)	0 (0)	0.41 (68)	10.75 (912)	24.42 (2120)	1.54 (263)	0.34 (120)	0 (0)	0.07 (6)	0 (0)	0 (0)	0 (0)	3.94 (6501)	53.85	2.12	C
Crematogaster fauconneti	0 (0)	0 (0)	0 (0)	0.04 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (7)	7.69	0	Acl
Crematogaster gabonensis	0 (0)	12.23 (1540)	8.95 (420)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.19 (1960)	15.38	0.18	A
Crematogaster gambiensis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (3)	7.69	0	Acl
Crematogaster homeri	0 (0)	0.28 (35)	0 (0)	0 (0)	0 (0)	0 (0)	2.59 (444)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.29 (479)	15.38	0.04	Acl
Crematogaster painei	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.88 (250)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.15 (250)	7.69	0.01	Acl
Crematogaster rugosa	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.1 (17)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (17)	7.69	0	Acl
Crematogaster sp.1	0.03 (10)	0.17 (22)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (34)	23.08	0	Acl
Crematogaster sp.2	0.11 (37)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (37)	7.69	0	Acl
Monomorium	**0.01 (3)**	**0.19 (24)**	**0.11 (5)**	**0.65 (108)**	**0 (0)**	**0 (0)**	**0.04 (6)**	**9.88 (3475)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**2.19 (3621)**	**46.15**	1.01	**C**
Monomorium borlei	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.28 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.06 (100)	7.69	0	Acl
Monomorium oscaris	0 (0)	0 (0)	0.11 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (5)	7.69	0	Acl
Monomorium sp.1	0.01 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.04 (6)	9.6 (3375)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.05 (3384)	23.08	0.47	A
Monomorium sp.2	0 (0)	0.19 (24)	0 (0)	0.65 (108)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.08 (132)	15.38	0.01	Acl
Myrmicaria	**0 (0)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**7.69**	0	**Acl**
Myrmicaria natalensis	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Phasmomyrmex	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**7.69**	0	**Acl**
Phasmomyrmex sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Pheidole	**29.18 (9591)**	**14.57 (1834)**	**14.27 (670)**	**4.28 (707)**	**4.78 (405)**	**1.36 (118)**	**8.22 (1408)**	**9.39 (3300)**	**8.32 (700)**	**0.75 (66)**	**0 (0)**	**0.02 (2)**	**0.38 (4)**	**11.39 (18805)**	**92.31**	10.51	**C**
Pheidole albidula	0 (0)	3.97 (500)	0.02 (1)	0.04 (6)	0 (0)	0 (0)	1.79 (306)	0 (0)	8.32 (700)	0 (0)	0 (0)	0 (0)	0 (0)	0.92 (1513)	38.46	0.35	**A**
Pheidole custodiens	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl

Pheidole mayri	0 (0)	1.64 (207)	12.14 (570)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.47 (777)	15.38	0.07	Acl
Pheidole megacephala	10.95 (3600)	4.8 (604)	1.15 (54)	4.22 (697)	4.78 (405)	1.18 (102)	5.73 (981)	9.39 (3300)	0 (0)	0.59 (52)	0 (0)	0 (0)	0 (0)	5.93 (9795)	69.23	4.11	C
Pheidole mentita	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.09 (8)	0 (0)	0 (0)	0 (0)	0 (8)	7.69	0	Acl
Pheidole minima	8.39 (2757)	4.15 (523)	0.96 (45)	0.02 (3)	0 (0)	0.17 (15)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2.02 (3344)	46.15	0.93	**C**
Pheidole pulchella	0.03 (11)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.38 (4)	0.01 (15)	15.38	0	Acl
Pheidole rohani	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Pheidole sp.1	2.5 (823)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (2)	0 (0)	0.5 (825)	15.38	0.08	Acl
Pheidole sp.2	7.3 (2400)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.45 (2400)	7.69	0.11	A
Pheidole sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.7 (120)	0 (0)	0 (0)	0.07 (6)	0 (0)	0 (0)	0 (0)	0.08 (126)	15.38	0.01	Acl
Tetramorium	**0 (0)**	**0.01 (1)**	**0 (0)**	**0.28 (46)**	**0.09 (8)**	**0 (0)**	**0 (0)**	**1.76 (620)**	**0.02 (2)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.41 (677)**	**38.46**	0.16	**A**
Tetramorium coloreum	0 (0)	0 (0)	0 (0)	0.04 (6)	0.09 (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (14)	15.38	0	Acl
Tetramorium guineense	0 (0)	0.01 (1)	0 (0)	0.24 (40)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (43)	23.08	0.01	Acl
Tetramorium sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.76 (620)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.38 (620)	7.69	0.03	Acl
Tetramorium	0 (0)	0.03 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (4)	7.69	0	Acl
Tetramorium guineensis	0 (0)	0.03 (4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (4)	7.69	0	Acl
Ponerinae	**0.01 (3)**	**0.05 (6)**	**0.3 (14)**	**0.36 (59)**	**0 (0)**	**0 (0)**	**0.16 (28)**	**0.01 (3)**	**0 (0)**	**0.03 (3)**	**0 (0)**	**0.06 (5)**	**0.28 (3)**	**0.08 (124)**	69.23	0.05	Acl
Anochetus	**0 (0)**	**0 (0)**	**0 (0)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**7.69**	0	**Acl**
Anochetus nsp Cameroon FK	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Hypoponera	**0 (0)**	**0.02 (2)**	**0.04 (2)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0.05 (8)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.01 (13)**	**30.77**	0	**Acl**
Hypoponera cognata	0 (0)	0 (0)	0.04 (2)	0 (0)	0 (0)	0 (0)	0.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (5)	15.38	0	Acl
Hypoponera intermedia	0 (0)	0.02 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (7)	15.38	0	Acl
Hypoponera sp.	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Leptogynys	**0.01 (3)**	**0.03 (4)**	**0.26 (12)**	**0.34 (56)**	**0 (0)**	**0 (0)**	**0.12 (20)**	**0 (0)**	**0 (0)**	**0.03 (3)**	**0 (0)**	**0.06 (5)**	**0.28 (3)**	**0.06 (106)**	**61.54**	0.04	**Acl**
Leptogenys crustosa	0 (0)	0 (0)	0 (0)	0.33 (55)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (55)	7.69	0	Acl
Leptogenys sp.2	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Leptogynys conradti	0.01 (3)	0 (0)	0.19 (9)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (12)	15.38	0	Acl
Leptogynys intermedia	0 (0)	0.03 (4)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (3)	0 (0)	0.06 (5)	0.28 (3)	0.01 (16)	38.46	0	**Acl**
Leptogynys sp.1	0 (0)	0 (0)	0.04 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (2)	7.69	0	Acl
Leptogynys vindicis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.12 (20)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (20)	7.69	0	Acl
Ondontomachus	**0 (0)**	**0 (0)**	**0 (0)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**7.69**	0	**Acl**
Odontomachus troglodytes	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	7.69	0	Acl
Ponera	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.01 (3)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (3)**	**7.69**	0	**Acl**
Ponera sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (3)	7.69	0	Acl

The grey color denotes the commonly eaten preys. Ar= relative abundance; Fo= frequency of occurrence; RI=relative importance of prey; WBP= white-bellied pangolin
C= Constant or common prey/consumed preferentially; A= Accessory or less common prey/ secondarily consumed; Acl= Accidentally or uncommon prey/rarely eaten

Appendix 12:Actual and relative abundance of termite species eaten by white-bellied pangolin individuals in this study

	WBP01	**WBP02**	**WBP03**	**WBP04**	**WBP05**	**WBP06**	**WBP07**	**WBP08**	**WBP09**	**WBP10**	**WBP11**	**WBP12**	**WBP13**	**Total Ar**	**Fo**	**RI**	**Cat**
Blattodea	**14.89 (4893)**	**16.61 (2091)**	**35.28 (1656)**	**86.38 (14254)**	**52.8 (4478)**	**61.51 (5339)**	**23.94 (4101)**	**40.08 (14091)**	**62.38 (5247)**	**21.96 (1943)**	**48.78 (942)**	**68.29 (6016)**	**40.43 (431)**	**39.65 (65482)**	**100**	39.65	C
Rhinotermitidae	**1 (330)**	**0.01 (1)**	**0.28 (13)**	**0.4 (66)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.17 (15)**	**1.22 (13)**	**0.27 (439)**	**53.85**	0.14	A
Coptotermitinae	**0 (0)**	**0.01 (1)**	**0.06 (3)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (4)**	**23.08**	0	Acl
Coptotermes (1)	0 (0)	0.01 (1)	0.06 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (4)**	23.08	**0**	Acl
Coptotermes sjostedti **Holmgren, 1911**	0 (0)	0.01 (1)	0.06 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (4)**	23.08	0	Acl
Rhinotermitinae	**1 (330)**	**0 (0)**	**0.21 (10)**	**0.4 (66)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.17 (15)**	**1.22 (13)**	**0.26 (435)**	**46.15**	0.12	**A**
Schedorhinotermes (3)	1 (330)	0 (0)	0.21 (10)	0.4 (66)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.17 (15)	1.22 (13)	**0.26 (435)**	46.15	0.12	**A**
Schedorhinotermes lamanianus	1 (330)	0 (0)	0.21 (10)	0.4 (66)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.25 (407)**	30.77	0.08	**Acl**
Schedorhinotermes putorus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.17 (15)	1.22 (13)	**0.02 (28)**	15.38	0	Acl
Termitidae	**13.88 (4563)**	**16.6 (2090)**	**35 (1643)**	**85.98 (14188)**	**52.79 (4477)**	**61.51 (5339)**	**23.94 (4101)**	**40.08 (14091)**	**62.38 (5247)**	**21.96 (1943)**	**48.78 (942)**	**68.12 (6001)**	**39.21 (418)**	**39.38 (65043)**	**100**	39.38	C
Amitermitinae	**0 (0)**	**0.11 (14)**	**0.11 (5)**	**0.41 (68)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.05 (87)**	**23.08**	0.01	Acl
Ancistrotermes (1)	0 (0)	0 (0)	0.06 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (3)**	7.69	0	Acl
Ancistrotermes crucifer	0 (0)	0 (0)	0.06 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (3)**	7.69	0	Acl
Microcerotermes (4)	0 (0)	0.11 (14)	0.04 (2)	0.41 (68)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.05 (84)**	23.08	0.01	Acl
Microcerotermes edentatus	0 (0)	0.11 (14)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.01 (15)**	15.38	0	Acl
Microcerotermes parvus	0 (0)	0 (0)	0 (0)	0.3 (50)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.03 (50)**	7.69	0	Acl

Microcerotermes progrediens	0 (0)	0 (0)	0 (0)	0.11 (18)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.01 (18)**	7.69	0	Acl
Microcerotermes silvestrianus	0 (0)	0 (0)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (1)**	7.69	0	Acl
Cubitermitinae	**0.04 (13)**	**0.02 (3)**	**0.06 (3)**	**0.01 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.01 (20)**	**30.77**	0	**Acl**
Isognathotermes (2)	0.04 (13)	0.02 (3)	0.02 (1)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.01 (18)**	30.77	0	**Acl**
Isognathotermes zenkeri	0 (0)	0 (0)	0.02 (1)	0.01 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (2)**	15.38	0	Acl
Isognathotermes sp.	0.04 (13)	0.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.01 (16)**	15.38	0	Acl
Ophiotermes (1)	0 (0)	0 (0)	0.04 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (2)**	7.69	0	Acl
Ophiotermes ugandaensis	0 (0)	0 (0)	0.04 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (2)**	7.69	0	Acl
Macrotermitinae	**2.56 (842)**	**15.87 (1998)**	**32.59 (1530)**	**7.21 (1190)**	**1.57 (133)**	**61.51 (5339)**	**21.51 (3684)**	**7.21 (2536)**	**61.16 (5144)**	**13.96 (1235)**	**31.9 (616)**	**22.17 (1953)**	**38.18 (407)**	**16.11 (26607)**	**100**	16.11	C
Acanthotermes (1)	0 (0)	0 (0)	0.15 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (2)	0.33 (29)	0 (0)	2.24 (197)	6.38 (68)	**0.18 (303)**	38.46	0.07	**Acl**
Acanthotermes acanthothorax	0 (0)	0 (0)	0.15 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (2)	0.33 (29)	0 (0)	2.24 (197)	6.38 (68)	**0.18 (303)**	38.46	0.07	**Acl**
Allodontotermes (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.16 (14)	0 (0)	0.17 (15)	0 (0)	**0.02 (29)**	15.38	0	Acl
Allodontotermes sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.16 (14)	0 (0)	0.17 (15)	0 (0)	**0.02 (29)**	15.38	0	Acl
***Ancistrotermes* (1)**	**0.06 (21)**	**0.12 (15)**	**0.77 (36)**	**0.35 (58)**	**0.55 (47)**	**0 (0)**	**0.29 (50)**	**0 (0)**	**1.85 (156)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.23 (383)**	53.85	0.12	A
Ancistrotermes crucifer	0.06 (21)	0.12 (15)	0.77 (36)	0.35 (58)	0.55 (47)	0 (0)	0.29 (50)	0 (0)	1.85 (156)	0 (0)	0 (0)	0 (0)	0 (0)	**0.23 (383)**	53.85	0.12	A
Macrotermes (4)	0 (0)	0.33 (41)	29.27 (1374)	1.73 (285)	0.21 (18)	0 (0)	15.81 (2708)	1.96 (690)	0.1 (8)	3.15 (279)	0 (0)	2.28 (201)	4.88 (52)	**3.42 (5656)**	76.92	2.63	C
Macrotermes bellicosus	0 (0)	0.33 (41)	0 (0)	1.48 (245)	0 (0)	0 (0)	15.31 (2622)	1.39 (490)	0.1 (8)	0.71 (63)	0 (0)	0.11 (10)	0 (0)	**2.11 (3479)**	53.85	1.13	C
Macrotermes lilljeborgi	0 (0)	0 (0)	0 (0)	0.24 (40)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.02 (2)	0 (0)	0 (0)	0 (0)	**0.03 (42)**	15.38	0	Acl
Macrotermes amplus	0 (0)	0 (0)	29.27 (1374)	0 (0)	0.21 (18)	0 (0)	0 (0)	0.57 (200)	0 (0)	2.42 (214)	0 (0)	2.17 (191)	4.88 (52)	**1.24 (2049)**	46.15	0.57	**C**
Macrotermes sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.5 (86)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.05 (86)**	7.69	0	Acl

***Microtermes* (2)**	0 (0)	0 (0)	0.04 (2)	0 (0)	0.02 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	**0 (5)**	23.08	0	Acl
Microtermes hospes	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	0 (0)	**0 (1)**	7.69	0	Acl
Microtermes osborni	0 (0)	0 (0)	0.04 (2)	0 (0)	0.02 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (4)**	15.38	0	Acl
***Odontotermes* (8)**	0 (0)	6.61 (832)	0.02 (1)	1.46 (241)	0 (0)	0 (0)	0 (0)	0.05 (17)	0.75 (63)	1.51 (134)	31.9 (616)	1.07 (94)	0 (0)	**1.21 (1998)**	61.54	0.74	C
Odontotermes culturarum Sjöstedt, 1924	0 (0)	0.06 (7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (7)**	7.69	0	Acl
Odontotermes flammifrons (Sjöstedt, 1926)	0 (0)	3.24 (408)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.25 (408)**	7.69	0.02	Acl
Odontotermes fulleri (Emerson, 1928)	0 (0)	0 (0)	0.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (1)**	7.69	0	Acl
Odontotermes lacustris	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.05 (17)	0 (0)	1.51 (134)	8.44 (163)	0.5 (44)	0 (0)	**0.22 (358)**	30.77	0.07	**Acl**
Odontotermes munkibunginis	0 (0)	2.68 (337)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.75 (63)	0 (0)	0 (0)	0 (0)	0 (0)	**0.24 (400)**	15.38	0.04	Acl
Odontotermes natalensis	0 (0)	0.64 (80)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.05 (80)**	7.69	0	Acl
Odontotermes sp.	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	23.46 (453)	0.57 (50)	0 (0)	**0.3 (503)**	15.38	0.05	Acl
Odontotermes stanleyvilleinsis	0 (0)	0 (0)	0 (0)	1.46 (241)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.15 (241)**	7.69	0.01	Acl
***Protermes* (1)**	0 (0)	0.22 (28)	0 (0)	0 (0)	0 (0)	0 (0)	0.15 (25)	0 (0)	0.67 (56)	0 (0)	0 (0)	0 (0)	0 (0)	**0.07 (109)**	23.08	0.02	Acl
Protermes hirticeps	0 (0)	0.22 (28)	0 (0)	0 (0)	0 (0)	0 (0)	0.15 (25)	0 (0)	0.67 (56)	0 (0)	0 (0)	0 (0)	0 (0)	**0.07 (109)**	23.08	0.02	Acl
***Pseudacanthotermes* (1)**	2.5 (821)	8.6 (1082)	2.34 (110)	3.67 (606)	0.78 (66)	61.51 (5339)	5.26 (901)	5.2 (1829)	57.77 (4859)	8.79 (778)	0 (0)	16.41 (1446)	26.92 (287)	**10.97 (18124)**	92.31	10.13	C
Pseudacanthotermes militaris	2.5 (821)	8.6 (1082)	2.34 (110)	3.67 (606)	0.78 (66)	61.51 (5339)	5.26 (901)	5.2 (1829)	57.77 (4859)	8.79 (778)	0 (0)	16.41 (1446)	26.92 (287)	**10.97 (18124)**	92.31	10.13	C
Nasutermitinae	**10.04 (3300)**	**0.6 (75)**	**2.24 (105)**	**62.65 (10338)**	**50.71 (4301)**	**0 (0)**	**2.37 (406)**	**31.01 (10901)**	**0.33 (28)**	**7.36 (651)**	**16 (309)**	**44.63 (3932)**	**0.84 (9)**	**20.8 (34355)**	**92.31**	19.2	C
***Nasutitermes* (2)**	10.04 (3300)	0.6 (75)	2.24 (105)	62.65 (10338)	5.79 (491)	0 (0)	2.37 (406)	31.01 (10901)	0.33 (28)	7.36 (651)	16 (309)	44.63 (3932)	0.84 (9)	**18.49 (30545)**	92.31	17.07	C
Nasutitermes arborum	10.04 (3300)	0.6 (75)	2.24 (105)	62.64 (10337)	5.79 (491)	0 (0)	0.04 (6)	31.01 (10901)	0.33 (28)	7.36 (651)	16 (309)	44.63 (3932)	0.84 (9)	**18.25 (30144)**	92.31	16.85	C
Nasutitermes fulleri	0 (0)	0 (0)	0 (0)	0.01 (1)	0 (0)	0 (0)	2.34 (400)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.24 (401)**	15.38	0.04	Acl

***Trinervitermes* (1)**	0 (0)	0 (0)	0 (0)	0 (0)	44.92 (3810)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**2.31 (3810)**	7.69	0.18	A
Trinervitermes occidentalis	0 (0)	0 (0)	0 (0)	0 (0)	44.92 (3810)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**2.31 (3810)**	7.69	0.18	A
Sphaerotermitinae	**1.24 (408)**	**0 (0)**	**0 (0)**	**1.09 (180)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0.59 (52)**	**0 (0)**	**0 (0)**	**0.19 (2)**	**0.39 (642)**	**30.77**	0.12	**A**
***Sphaerotermes* (2)**	1.24 (408)	0 (0)	0 (0)	1.09 (180)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.59 (52)	0 (0)	0 (0)	0.19 (2)	**0.39 (642)**	30.77	0.12	**A**
Sphaerotermes sphaerothorax	1.24 (408)	0 (0)	0 (0)	1.09 (180)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.59 (52)	0 (0)	0 (0)	0.19 (2)	**0.39 (642)**	30.77	0.12	**A**
Termitidae sbfam	0 (0)	0 (0)	0 (0)	14.61 (2411)	0.51 (43)	0 (0)	0.06 (11)	1.86 (653)	0.89 (75)	0.06 (5)	0.88 (17)	0.4 (35)	0 (0)	**1.97 (3250)**	61.54	1.21	C
Termitidae gen 1 (1)	0 (0)	0 (0)	0 (0)	14.61 (2411)	0.51 (43)	0 (0)	0.06 (11)	0.15 (53)	0.89 (75)	0.06 (5)	0.88 (17)	0.06 (5)	0 (0)	**1.59 (2620)**	61.54	0.98	C
Termitidae sp.1	0 (0)	0 (0)	0 (0)	14.61 (2411)	0.51 (43)	0 (0)	0.06 (11)	0.15 (53)	0.89 (75)	0.06 (5)	0.88 (17)	0.06 (5)	0 (0)	**1.59 (2620)**	61.54	0.98	C
Termitidae gen 2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (10)	0 (0)	**0.01 (10)**	7.69	0	Acl
Termitidae sp.2	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (10)	0 (0)	**0.01 (10)**	7.69	0	Acl
Termitidae gen 3 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.23 (20)	0 (0)	**0.01 (20)**	7.69	0	Acl
Termitidae sp.3	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.23 (20)	0 (0)	**0.01 (20)**	7.69	0	Acl
Termitidae gen 4 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.71 (600)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.36 (600)**	7.69	0.03	Acl
Termitidae sp. 4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.71 (600)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0.36 (600)**	7.69	0.03	Acl
Termitinae	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (0)**	**0 (1)**	**7.69**	0	Acl
***Pericapritermes* (1)**	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (1)**	7.69	0	Acl
Pericapriterms urgens	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	**0 (1)**	7.69	0	Acl

Appendix 13: Some ant prey species preferentially eaten by white-bellied pangolin

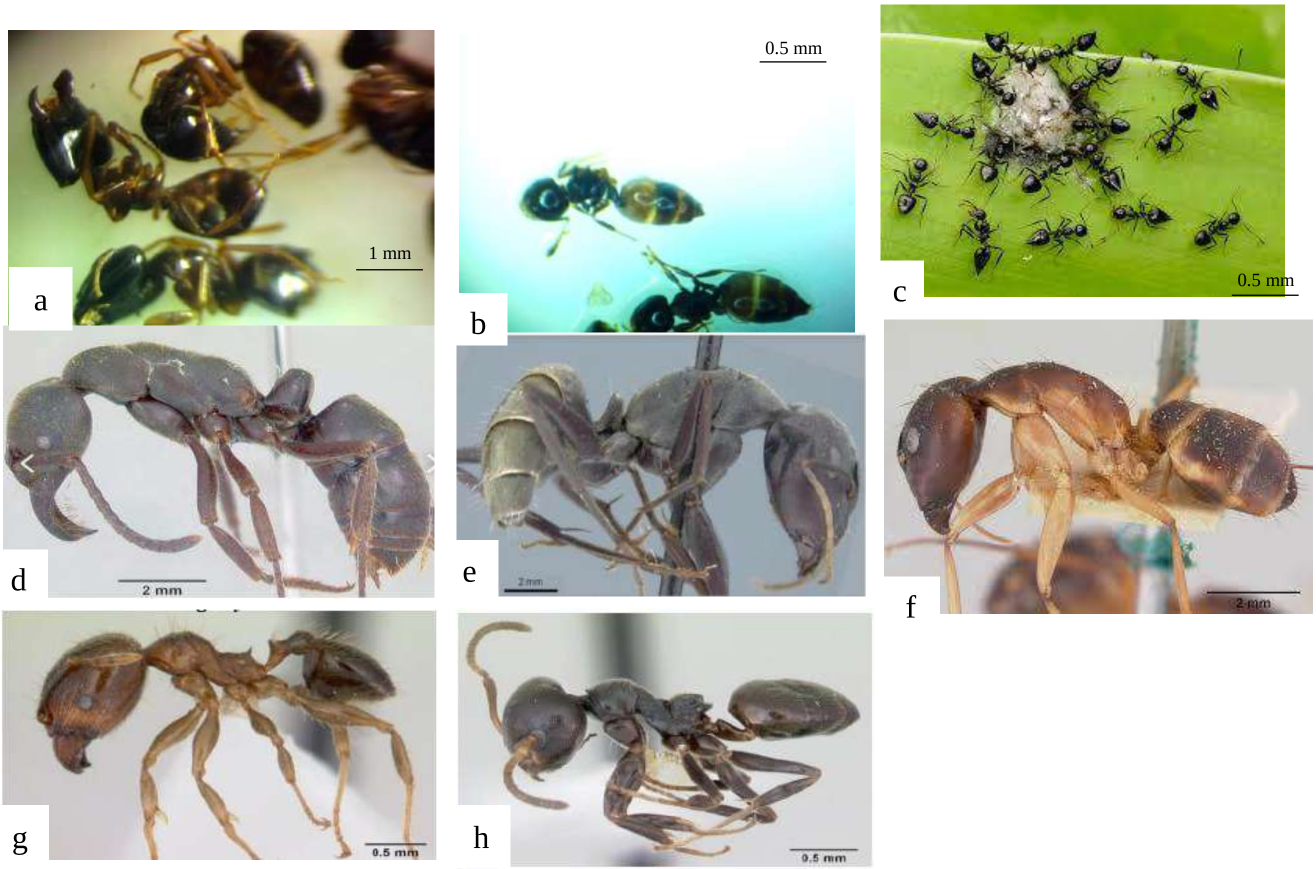

Figure 68: Ant prey species eaten by white-bellied pangolin (a, b, c, d) =Preferential or common ant prey species eaten (a) *Camponotus chapini* (b) *Crematogaster acis*, *(c) Crematogaster concava*, *(d) Palthotyreus tarsatus*; (e: *Camponotus flavomarginatus*; f, *Camponotus brutus*; g: *Pheidole megacephala*)= secondarily or less commonly eaten prey (h), *Axinidris* sp.1 and accidentally or uncommon prey/rarely eaten.

Sources: Author (a,b) and ants of africa.org (c, d, e, f, g)

Appendix 14: Codes of the ant and termite prey species names on the correspondence analysis figures

The codes of species name are made by the two first letters of the name of genus followed by the two letters of the name of species (e.g., Cabr=*Camponotus brutus*) or the two letters of the genus name followed by the symbol sp. Or the two letters of the genus name followed by the two letters of the subgenus name into brackets (e.g., Ca (Ta)sp. =*Camponotus* (*Tanaemyrmex*) sp.)

Anca=Anoplolepis carinata (Emery, 1899)
Ansp.=Ancistrotermes sp.
Arbe=Anochetus bequarti
Asp.=Anoplolepis sp.
Ate=Anoplolepis tenella (Santschi, 1911)
Asp.=Anochetus nsp Cameroon FK
Axsp. 1=Axinidris sp.1
Cabr= Camponotus brutus Forel, 1886
Axbi=Axinidris bidens

Codes	**Name of species**
Alsp.1	*Allodontotermes* sp.1

Ca(Ta)sp. =Camponotus (Tanaemyrmex) sp.
Axisp. 2=Axinidris sp.2
Ca(Pa)sp. =Camponotus (Paramymablys) sp.
Caac= Camponotus acvapimensis
Axmu=Axinidris murialae
Cafl=Camponotus flavomaginatus
Crsp. 2=Crematogaster sp.2
Cach=Camponotus chapini
Crsp. 1= Crematogaster sp.1
Cama=Camponotus maculatus
Catgu=Cataulacus guineensis
Cr(Ox)sp. 1= Crematogaster (Oxygyne) sp.1
Cr(De)sp.1=Crematogaster (Decacrema) sp.1
Cr(Ox)sp. 2=Crematogaster (Oxygyne) sp.2
Crho=Crematogaster homeri
Crga=Crematogaster gabonensis
Cr(Or)sp. 2=Crematogaster (Orthocrema) sp.2
Cr(Sp)sp.1=Crematogaster (Sphaerorema) sp.1
Carsp. =Cardiocondyla sp.
Crru=Crematogaster rugosa
Crgam=Crematogaster gambiensis
Cr(Cr)sp. =Crematogaster (Crematogaster) sp.
Casi=Camponotus simus
Cachr=Camponotus chrysurus
Dni= *Dorylis nigricans*
Hco= Hypoponera cognata
Lmo=*Lepisiota monardi* Santshi, 1930
Olo= *Oecophila longinoda*
Pode= Polyrachis decemdetata
Pomi= Polyrachis militaris
Pta= Paltothyreus tarsatus
Phal= Pheidole albidula
Phme= Pheidole megacephala
Phrga Phrynoponera gabonensis
Phspe= Pheidole speculifera
Tecsp2= Technomyrmex sp.2
Teac= Tetramorium acculeatum
Tme= Tapinoma meganocphala
Tega=Tetramorium gabonense
Teco= Tetramorium coloreum

Cusp.	*Isognathotermes sp.*
Cosj	*Coptotermes sjostedti*
Isze	*Isognathotermes zenkeri*
Isfi	*Isognathotermes finitimus* (Schmitz, 1916)
Isbu	*Isognathotermes bulbifrons* (Sjöstedt, 1924)
Crmi	*Crenetermes mixtus*
Cusu	*Isognathotermes subarquatus*
Cusp.2	*Isognathotermes* sp.2
Isfu	*Isognathotermes fungifaber* (Sjöstedt, 1896)
Nisa	*Nitiditermes sankurensis*
Isga	*Isognathotermes gaigei*
Isug	*Isognathotermes ugandensis*
Iscg	*Isognathotermes congoensis*
Cosp.	*Coxotermes* sp.
Nior	*Nitiditermes orthognathus*
Issc	*Isognathotermes schmidti*
Isfu	*Isognathotermes fungifaber*
Isbu	*Isognathotermes bulbifrons*

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Understanding Local Ecological Knowledge, Ethnozoology, and Public Opinion to Improve Pangolin Conservation in the Center and East Regions of Cameroon

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Abstract. African pangolins are exceptionally difficult to monitor in the wild, which means that assessing threats and impacts to these species also remains a challenge. Local ecological knowledge (LEK) surveys have been recommended as an important tool to collect data for small elusive species. We carried out community-based interviews in 20 villages surrounding Mpem et Djim and Deng-Deng National Parks to gather information on local ecological and traditional medicine knowledge, perceived population status, and the level of conservation awareness amongst local people concerning giant pangolin (*Smutsia gigantea*), white-bellied pangolin (*Phataginus tricuspis*), and black-bellied pangolin (*Phataginus tetradactyla*). The arboreal black-bellied pangolin was least known by local people, and along with the giant pangolin was the least recently observed species. The white-bellied pangolin was reported to be the most recently observed species by most people. Local people reported seeing giant pangolins most around forest and savannah burrows and white-bellied pangolins in forests, commonly crossing dead fallen trees. Limited traditional or cultural uses of pangolins were reported, and most respondents were aware of threats to pangolins. Respondents showed great interest in pangolin conservation, suggesting various strategies for conservation activities, such as trade controls and creation of alternative sources of food. We show that working with local communities can provide useful information for pangolin conservation and management efforts within protected areas.

Keywords: Cameroon, local ecological knowledge, Pholidota, traditional medicine, use

Introduction

Pangolins (Pholidota: Manidae) are a unique and evolutionarily distinct group of eight mammal species distributed across parts of Asia and Africa (Bräutigam et al. 1994; Gaubert et al. 2018). They are characterized by their overlapping keratinous scales that cover most of their body, are solitary and, with the exception of the black-bellied pangolin (*Phataginus tetradactyla*), are largely nocturnal (Newton et al. 2008; Willcox et al. 2019). Their ecological traits and behaviors, such as poor eyesight and their mechanism of defense, make them highly susceptible to overexploitation (Sodeinde and Adedipe 1994). All eight species of pangolin are globally threatened due to both local demand in pangolin range states and increasing international demands for pangolin scales in parts of Asia (IUCN 2019). Populations of Asian pangolins have severely declined as a result (e.g., Loucks et al. 2009; Wu et al. 2004) and, simultaneously, the intercontinental trade and trafficking of African pangolin scales has emerged in the last decade (Heinrich et al. 2016; Ingram et al. 2019a), potentially amplified by the growing economic ties

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between the African and Asian continents (Constantaras 2016; Mambeya et al. 2018). As such, pangolins are listed on Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2017). Yet, pangolins remain one of the least understood groups of mammals in terms of their ecology and behavior, hindering conservation efforts (Ingram et al. 2019b; Willcox et al. 2019).

African pangolins are distributed across different parts of sub-Saharan Africa and three of the four African species are distributed across tropical West and Central Africa (Kingdon and Hoffman 2013), where they are consumed as bushmeat in both rural and sometimes urban areas (Ingram et al. 2018). Furthermore, in West Africa, pangolins are reportedly used by local people for traditional medicine (Boakye et al. 2014, 2015; Soewu and Adoyele 2009; Soewu et al. 2020), but less is known about the perceived medicinal and cultural value of pangolins to people in Central African countries. Cameroon has been identified as one of the countries most involved in the trafficking of pangolin scales (Ingram et al. 2019a). Since the transfer of pangolins to CITES Appendix I, pangolins have now been classified as a Class A species in Cameroon, affording them the highest level of protection (MINFOF 2017). In a recent revision of the conservation status of pangolins, the giant pangolin (*Smutsia gigantea*) was listed as "Endangered" principally due to the increasing risks posed by overexploitation and habitat loss throughout its range (Pietersen et al. 2019). Given the pressures that pangolins in Cameroon face, it is important to understand pangolin population status, current use levels (e.g., traditional medicine), and local awareness of threats to pangolins.

Data on pangolin life history traits and ecology can be challenging to obtain due to their low population density and their limited detectability through common monitoring approaches effective for other mammals (Nash et al. 2016; Shek et al. 2007; Willcox et al. 2019; Wu et al. 2004). Particularly for rare and elusive species, local ecological knowledge (LEK), usually referring to the environmentally related knowledge acquired over the lifetime of individuals developed through interactions with the natural environment (Gilchrist et al. 2005), has been shown to be an important tool to inform conservation management decisions and has been increasingly applied (Golden et al. 2013; Nash et al. 2016; Segan et al. 2010; Sutherland et al. 2004). LEK surveys can be considered as an important complementary method to obtain useful data relevant to conservation, especially for large-bodied vertebrates, such as occurrence data and information on cultural use and local perspectives on conservation (Meijaard et al. 2011; Parry and Perez 2015; Turvey et al. 2015). While, in some places, small- to medium-sized species of mammals are sometimes misidentified by respondents (Turvey et al. 2014), Nash et al. (2016) have recently used this method successfully to inform relevant ecological features of the Chinese pangolin (*Manis pentadactyla*). Given that African pangolins are morphologically distinct from other animals due to their scales and the fact that they have high consumptive, economic, and cultural value, it is likely that pangolins can be identified by untrained individuals, and, therefore, constitute a useful target species for LEK-based research (Nash et al. 2016; Newton et al. 2008; Thapa et al. 2014). Furthermore, interview-based methods have been successfully conducted elsewhere to collect data on the LEK and traditional knowledge (i.e., knowledge handed down over generations [Gilchrist et al. 2005]) of pangolins from hunters, market traders, and forest workers (Nash et al. 2016; Newton et al. 2008; Sodeinde and Adedipe 1994).

In Cameroon, ecological information on pangolins from field studies remains limited. Kingdon and Hoffman (2013) recorded the presence of giant pangolin near the band of the Sanaga River and Bruce et al. (2018a, 2018b) recorded white-bellied pangolin (*Phataginus tricuspis*) and giant pangolin in the Dja Fauna Reserve using camera traps. Recently, Ichu et al. (2017) assessed the status of three pangolin species in Campo Ma'an and Mbam et Djerem National Parks and the Dja Faunal Reserve using LEK, but data from other areas of Cameroon are still lacking.

Here, we gather information on local ecological and traditional knowledge from local communities surrounding two protected areas located in the Center and East regions of Cameroon, using interview surveys. This is intended to help gain a preliminary understanding of 1) the features of pangolin ecology and population status that can be obtained using LEK; 2) the perceived medicinal and cultural value of pangolin; and 3) the attitudes of local people towards potential pangolin conservation actions.

Methods

Study Area

The survey was carried out in villages around two national parks in Cameroon: Mpem et Djim National Park (MDNP) located in the Center Region, and Deng-Deng National Park (DDNP) in the East Region (Figure 1). Both national parks are located in the transition zone between the savannah and forest habitats (Dames and Moore 1999), and are surrounded by several villages. Populations surrounding these parks belong to several ethnic groups, primarily Babouté and Baveck around MDNP and Képéré, Boblis, Pôl, and Gbaya around DDNP (Diangha 2015).

Survey Method

Field work was carried out between March 8–16, 2018, at DDNP and from August 21 to September 3, 2018, at MDNP. Following Nash et al. (2016), we randomly selected 20 villages that were 1) located within 7 km of each national park and 2) safe to visit at the time of the survey. Local guides able to translate introduced us to local people suspected to have good LEK (Ichu et al. 2017) and enabled us to preclude people of less than ten years of permanent residency in the villages. In each village, we conducted interviews with ≥ ten people, to allow for adequate response saturation levels (Guest 2006; Nash et al. 2016; White et al. 2005). A pre-survey was performed to train the research team of three interviewers to standardize the survey approach, minimize variability, and evaluate the time involved to complete one interview.

Each interview (lasting < 1 hour) was conducted as a proactive conversation, with one individual using a semi-structured questionnaire comprised of both open-ended and close-ended questions (Boakye et al. 2015; Ichu et al. 2017; Nash et al. 2016). The questionnaire firstly addressed the demographic information (e.g., sex, age) of the respondents. They were then asked to identify a series of animal photos by name (in French or their local language). To check for response reliability, we used a negative control photo of a brown bear (*Ursus arctos*) that was not native to Africa (following Turvey et al. 2014). Subsequently photos of an African Golden cat (*Caracal aurata*), and giant, black-bellied, and white-bellied pangolins were used as positive controls. For each species, respondents were then asked whether they had seen each animal before and, if so, they were asked when and where they had seen the species and when they had seen each species for the last time. Additionally, we asked the respondent about their perception of the current population size of each species based on their experience of seeing pangolins; responses were categorized as low (for species rarely sighted), stable (for species regularly sighted), or high (for species frequently sighted). Respondents were also asked about their perception of pangolin ecology (e.g., nesting and feeding behavior, number of offspring).

The use of pangolins for traditional medicine was investigated using

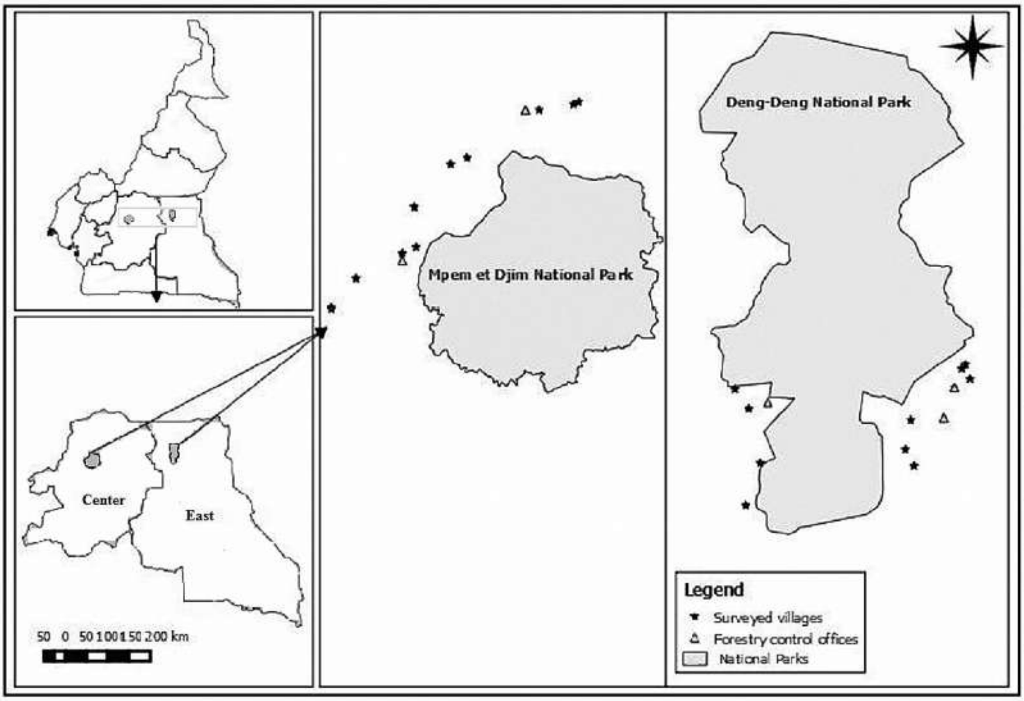

Figure 1. Locations of the surveyed villages and forest offices surrounding MDNP and DDNP in Central and East Regions, Cameroon

open-ended questions when respondents were not traditional medicine practitioners to avoid unintentionally suggesting any perceived medicinal value (Nash et al. 2016). We investigated various important issues of pangolin conservation, including awareness of the legality of pangolin hunting and trade and law enforcement activities by the wildlife protection authorities, such as arrests often observed in their villages and their opinion about such arrests. The respondents were also asked if they believed that pangolins were at risk of extinction (based on the individual's perception of past and current pangolin population trends and the threats that they consider pangolins to face locally) and the reasons for their belief; whether they agree with protecting pangolins; and what actions they think would improve conservation in the area.

We obtained authorization letters from government authorities and the University of Yaoundé I, and a permit from the Ministry of Forestry and Wildlife (MINFOF). Individual and community level ethical considerations were made following the International Society of Ethnobiology (ISE) Code of Ethics (ISE 2006), where possible, as follows. The survey team first introduced themselves to each surveyed village chief and then asked permission to conduct the study, presenting our institutional affiliation, authorization letters, and informing the chief of the survey objectives, benefits, and study period (translated in local languages where necessary). After agreeing to take part, the chief usually informed the whole village of our presence. Each interviewee's prior informed consent was obtained verbally (Akrim et al. 2017). Before each interview, respondents (all above 19 years old) were informed about the survey objectives, that they would remain anonymous on the questionnaire, and if necessary, were informed about Law N°91/023 (1991) stipulating that information collected from any survey questionnaire could not be used for control purposes. Respondents were informed that their participation was completely voluntary and they could abandon the interview at any point if they felt uncomfortable with questions. Questions were reformulated if respondents were not sure on the exact meaning and we asked for clarification of answers where necessary to ensure accuracy of the information.

Statistical Analysis

Data were analyzed using the software IBM© SPSS Statistics 20.0. We considered the response *petit pangolin* as the correct name for both white-bellied and black-bellied pangolins. Reported sightings of pangolins before 2016 were grouped into a unique answer category "before 2016." We performed univariate analyses of frequencies for qualitative non-dependent variables, including demography parameters, the number of respondents (n) who recognized each pangolin species, sighting locations, the year of the sighting, and medicinal and cultural use. We examined the perceived current pangolin population size and the number of each pangolin species sighted per national park according to the age and occupation of the respondents using bivariate analysis of the frequencies. Chi-square tests were used to compare the frequencies of responses between the age and occupation of respondents and national parks, and differences were considered significant at 5% level of probability.

Results

Demography of Respondents

In total, we interviewed 368 respondents belonging to 42 ethnic groups, although not all respondents answered every question, so n differs between questions. Almost all respondents (82.1%) were male and 17.7% were female (n = 367 responses), and most were Christian (84.2%), while only 15.0% were Muslim (n = 365). Most of the participants were aged between 25–45 years old (40.3%), while 27.5% were aged between 19–25 and 32.1% were aged above 45 years old (n = 367). Participants had mostly primary (44.0%) and secondary (45.1%) level of school education (n = 361). The main occupations of participants were farmers (69.3%), fishermen (9.2%), traders (8.4%), and hunters (8.0%) (n = 365). None reported being traditional medicine practitioners.

Identification of Pangolin Species

None of the respondents failed the negative control photo identification. Of the respondents, 95.4% (n = 351) recognized the giant pangolin and correctly named it in French (*pangolin géant*) or the equivalent in their native language. Among them, 92.4% (n = 350) had already seen this species. People aged between 25 and 35 years old recognized the giant pangolin most frequently (χ^2 [X = 4, N = 359] = 11.35, p = 0.02). The local names for pangolins varied among the ethnic groups of the villages located around the two protected areas in the Eastern and Center Regions (Table 1).

Almost all respondents (96.7%, n = 356) recognized the white-bellied pangolin and named it in French (*petit pangolin*) or in their native language (92.4%, n = 340). Of those who recognized the white-bellied pangolin, 92.7% (n = 341) admitted to having seen this species. Only 39.9% (n = 147) of interviewees were able to recognize and distinguish morphologically the black-bellied from the white-bellied pangolin (due to locally being considered unlucky—see section on cultural value) but did not name them differently in French. Respondents (27.2%, n = 100) reported the name as *petit pangolin*, the same as for the white-bellied pangolin, and only one respondent reported a local name of *koyo* (Table 1). Just 23.6% (n = 87) said they had seen the black-bellied pangolin. People aged between 45–55 years old were significantly more able to name the black-bellied pangolin in French (χ^2 [X = 4,

Table 1. Reported names of different pangolin species by ethnic groups located in the Center and East regions of Cameroon. Abbreviations: (n) indicates the number of respondents.

Ethnic groups	Relative frequency (n)	Giant pangolin	White-bellied pangolin	Black-bellied pangolin
Képéré	25.8 (95)	*ngouroumoutou*	*kéyé*	-
Boblis	2.7 (10)	*ivim*	*kâ*	-
Gbaya	15.2 (56)	*kakambia*	*sèvè/ kèkèyèkè*	-
Pôl	4.6 (17)	*phimo*	*sali*	-
Mbaki	2.2 (8)	*phimo*	*gâ*	-
Vouté/ Babouté	26.9 (99)	*ngouroumoutou*	*nga-nga*	*koyo*
Kako	<1 (3)	*bouya*	*ngao*	-

N = 184] = 16.46, p = 0.03), and were the age group to have most frequently seen this species (χ^2 [X = 4, N = 319] = 15.07, p = 0.005).

Location of Pangolin Sightings

Respondents reported seeing giant pangolins most frequently in the forest (40.2%, n = 148), but also alive or dead in villages (including wild and/or captive; 27.2%; n = 100), in savannah areas (23.3%, n = 99), and in local markets (20.9%, n = 77). In savannah habitat, giant pangolins were reportedly encountered at burrows (33.7%, n = 29), on the ground (24.1%, n = 26), on termite mounds (22.1%, n = 19) and ants' nests (15.1%, n = 13), and, sometimes, near swamp areas (11.6%, n = 10; Table 2). In the forest, giant pangolin was frequently sighted in burrows (19.7%, n = 14), on termite mounds (17.1%, n = 13), in swamp forest (17.1%, n = 13), and on the ground (15.5%, n = 11; Table 2).

White-bellied pangolin was most frequently sighted in forest habitat (51.9, n = 190), in villages (36.7%, n = 135) and markets (27.7%, n = 102), and savannah habitat (23.09%, n = 85) (Table 2). Farmers reported seeing the white-bellied pangolin in forests significantly more than in other locations (χ^2 [X = 4, N = 200] = 4.67, p = 0.03). In savannah habitat, this species was reported to be found predominantly near farms (5.6%, n = 20), but also on the ground (5.3%, n = 19), on trees (5.1%, n = 18)and on human paths. While in forest habitat, white-bellied pangolins were reported in a wide range of locations, but predominantly on trees (35.2 %, n = 81), fallen logs (34.5%, n = 80), on human paths (20.1%, n = 74), and on the ground (15.7%, n = 33).

The black-bellied pangolin was reported to be found most often in forest habitat (12.8%, n = 47) and in villages (5.9%, n = 22), and rarely in savannahs (2.9%, n = 10) and markets (1.9%, n = 7) (Table 2). Black-bellied pangolin was frequently reported to be found on palm trees and in swamp areas in both the savannah and forest habitats.

Perceived Pangolin Population Trends

Most of the respondents (61.0%, n = 119) mentioned seeing the giant pangolin around DDNP before 2016, while 58.3% (n = 62) of respondents around MDNP have reportedly seen them over the last three years (Figure 2). The number of people who had seen giant pangolins over the last three years was significantly lower in DDNP than in MDNP (χ^2 [X = 3, N = 303] = 20.83, p = 0.001). However, a significantly higher proportion of local residents perceived the population size of giant pangolins as being low in MDNP (68.9%) than in DDNP (49.2% of respondents; χ^2 [X = 3, N = 275] = 12.65, p = 0.005) (Figure 3).

Most of the respondents reported

Table 2. Percentage of respondents who reported seeing each species of pangolin in different broad location categories, and in more specific locations within forest and savannah habitat. Abbreviations: (n) indicates the number of respondents

General location	Specific location	Relative frequency (n)		
		Giant pangolin	White-bellied pangolin	Black-bellied pangolin
General sighting locations	Forest	40.2 (148)	51.9 (190)	12.8 (47)
	Savannah	23.3 (99)	23.09 (85)	2.9 (10)
	Market	20.9 (77)	27.7 (102)	1.9 (7)
	Village	27.2 (100)	36.7 (135)	5.9 (22)
Savannah	Human paths	0	1.6 (6)	3.4 (3)
	Near farms	1.16 (2)	5.6 (20)	4.5 (4)
	Ant's nests	15.1 (13)	0	0
	Termite's mounds	22.1 (19)	3.3 (11)	0
	Trees	0	5.1 (18)	0
	Lianas	0	0	0
	Palm trees	0	0	2.6 (2)
	Logs	0	3.5 (8)	0
	Burrows	33.7 (29)	0	0
	Swamp areas	11.6 (10)	0.8 (3)	11.6 (9)
	Ground	24.1 (26)	5.3 (19)	0
Forest	Human paths	0	20.1 (74)	0
	Near farms	0	14.4 (53)	0
	Ant's nests	6.08 (9)	0	0
	Termite's mounds	17.1 (13)	6.1 (13)	0
	Trees	9.46 (14)	35.2 (81)	0
	Lianas	0	1.3 (3)	0
	Palm trees	0	2.6 (6)	5.2 (7)
	Logs	2.70 (4)	34.5 (80)	0
	Burrows	19.7 (14)	0	0
	Swamp areas	17.1 (13)	10.5 (21)	3.2 (5)
	Ground	15.5 (11)	15.7 (33)	0

having seen white-bellied pangolin over the past three years both in DDNP (76.4%, n = 177) and in MDNP (73.7%, n = 90; Figure 2). Most sightings of white-bellied pangolins were in the year of the survey, 2018 (Figure 2). Hunters reported white-bellied pangolin more in 2018 than before 2016 compared to people with other occupations. Respondents had very mixed perceptions about the population status of white-bellied pangolins around both protected areas (Figure 3); almost half of respondents (45%) perceived the population size to be low while the other half perceived the population size to be high. The black-bellied pangolin was also reportedly seen most before 2016 (55.3%, n = 76 responses) by respondents around DDNP and by 50.0% (n = 9 responses) of respondents around MDNP (Figure 2). These sighting frequencies were not significantly different between the two protected areas

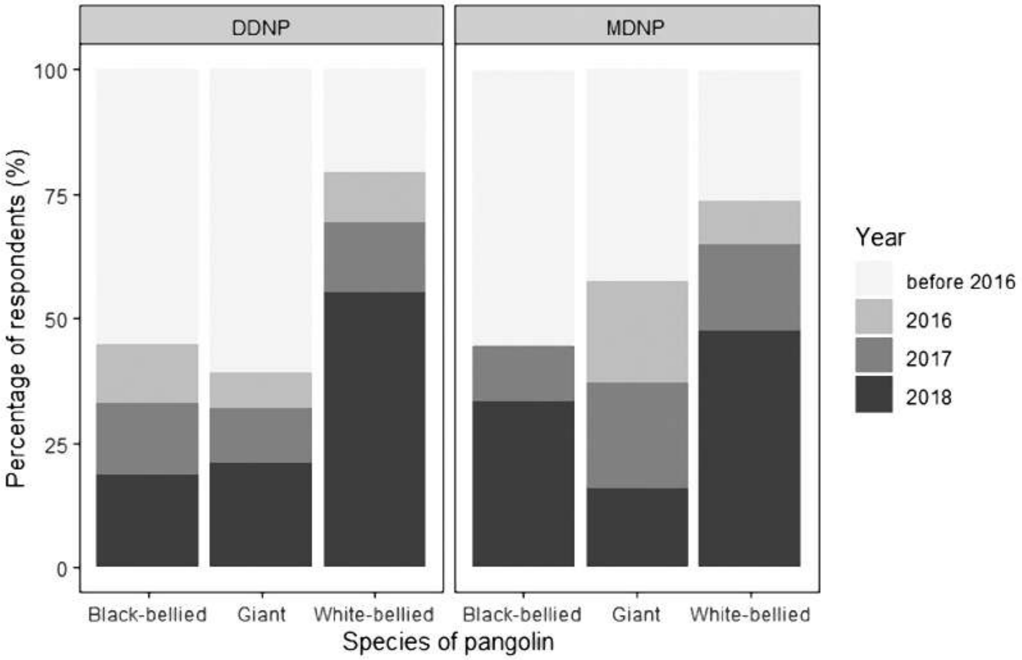

Figure 2. Proportion of respondents who had reported their last observation of each species of pangolin in a given year in the area around Deng-Deng National Park (DDNP) and Mpem and Djim National Park (MDNP). Percentages are calculated only from respondents who had seen each species.

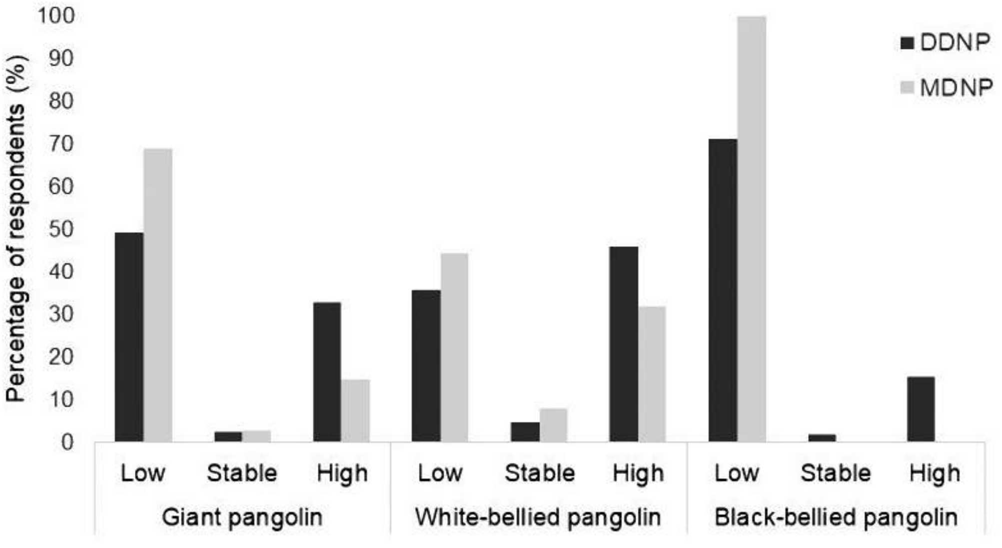

Figure 3. The perceived population size of each pangolin species amongst local people in Deng-Deng National Park (DDNP) and Mpem and Djim National Park (MDNP).

(χ^2 [X = 3, N = 85] = 2.02, p = 0.56). Black-bellied pangolin populations were perceived to be low by nearly all respondents in both DDNP (71.2%) and MDNP (100%; Figure 3).

Perceptions on Pangolin Behavior and Reproduction

Almost all respondents (86.7%) reported pangolins to be nocturnal, while 13.3% of people reported diurnal behavior (total n = 353 responses). Pangolins were also reported as solitary by 69.3% (n = 255) of respondents, but 23.1% (n = 85) reported that they had seen two pangolins together, and four respondents reported seeing pangolins mating. When two pangolins were reported together, respondents mentioned a male with a female (14.7%, n = 54) or a female with a juvenile (13.0%, n = 48) and, rarely, two juveniles (1.9%, n = 7). Most of the respondents (48.1%, n = 177) reported pangolins as having one offspring per birth, while 10.9% (n = 40) of them reported two or three offspring per birth, and 36.1% (133) of people did not know the number of offspring per birth. Most respondents (50.8%, n = 187) reported having no knowledge about the annual birth frequency of pangolins. Those who did stated that the frequency is once annually (24.7%, n = 91), while 4.6% (n = 17) of people believed the birth frequency to be more frequent. Most respondents knew that pangolins feed predominantly on ants (82.6%, n = 304) and termites (79.3%, n = 292), and never on herbs and leaves, but they also reported maggots, weaves, grasshoppers, mushroom (< 2% of respondents) often consumed by pangolins.

Cultural Beliefs and Medicinal Use of Pangolins

Of those who could identify the black-bellied pangolin, almost 70% (27.99% of total respondents) considered it unlucky when encountered during the daytime. Respondents often said that they did not want to encounter this particular species because seeing it was associated with death of the person or a family member, and they claimed that a ritual (not explained further) must be carried out to protect the person who had seen the black-bellied pangolin and the whole family from death. Another belief commonly heard among respondents (~80%) was the use of fresh pangolin scales placed into the ground with seeds as an agricultural practice. This is believed to improve yields of groundnuts (*Arachis hypogea*) and okra (*Abelmochus esculentus*). Beliefs about purported medicinal uses of pangolins were not reported among the communities we interviewed. One respondent from a region of Cameroon near the Nigeria border believed that fresh pangolin scales could be used as talismans against evil spirits.

Pangolins were largely not reported to have any medicinal uses in the study areas, with less than 1% (n = 3) of respondents stating that they recognized the use of pangolin scales in traditional medicine. Those who did report traditional medicine usage considered pangolin scales useful during pregnancy, suggesting that pangolins scales were used to increase lactation of pregnant women and to facilitate parturition.

Local Opinion about Pangolin Conservation and Threats

Most of the respondents around both protected areas considered pangolins to be at risk of extirpation (65.5%, n = 241), reporting pervasive hunting as the main reason (44.6%, n = 164; Table 3). Other reasons given include a decrease in pangolin population size, removal of pangolins from the area, low reproductive rate and vulnerable defense mechanism, increasing demand of scales, poor law enforcement, and wildfire and deforestation (logging) (Table 3). Those who did not consider pangolins at risk of extirpation (21.7%, n = 80) stated that it was because pangolin hunting is prohibited (5.7%, n = 21), that pangolins were abundant in the wild (9.0%, n = 33), that the national parks are playing a protection role (6.4, n = 18%), and that they believed pangolin populations to be increasing.

Nearly all respondents (82.1%, n = 302) stated that they were interested in pangolin conservation while 8.2% of people were not (n = 30). Almost all respondents

Table 3. Opinion of local respondents about whether they considered pangolins to be at risk of extinction in the area, and the reasons for or against. Abbreviations: (n) indicates the number of respondents.

Reasons for extinction risk	Relative frequency (n)	Reasons against extinction risk	Relative frequency (n)
Pervasive hunting	44.6 (164)	Hunting prohibition	7.5 (21)
Population decreasing and low reproduction rate	11.2 (38)	Abundant in the wild	12.7 (36)
People removing pangolins from the area	1.4 (4)	Park playing a protection role	6.4 (18)
Increasing demand for scales	1.9 (7)	No idea	5.3 (15)
Weak law enforcement	3.0 (11)		
Logging and wildfire	1.9 (7)		

knew that pangolin hunting and trade was forbidden (87.8%, n = 323), and 34.0% (n = 125) reported that people had been arrested in local villages for this infraction. When asked whether they believed that arresting people involved in pangolin hunting and trade was important for pangolin conservation, 60.9% (n = 224) agreed while 24.2% (n = 89) did not agree, and 3.5% (n = 13) of respondents could not give their opinion. A small proportion of respondents (5.3%, n = 19) asked why they should protect pangolins and some stated that they should be allowed to consume pangolin meat (2.2%, n = 8).

Suggestions for Conservation Improvement

Local people's suggestions to improve pangolin conservation in their area included controlling the pangolin trade (43.8%, n = 161), improving law enforcement (32.1%, n = 118), protecting pangolin habitats (35.9%, n = 132), and the development of alternative sources of food (39.4%, n = 145; Table 4). We also grouped suggestions into overarching themes of conservation strategy to highlight common topics (Table 4).

Table 4. Suggestions provided by local people to improve pangolin conservation. Respondents were able to provide more than one suggestion.

Theme	Suggestions of conservation strategies	Relative frequency (n)
Manage/ban trade	Control pangolin trade	43.8 (161)
	Establish a trade permit	<1 (1)
Manage/ban hunting	Control hunting practices	2.7 (10)
	Hunting prohibition	2.2 (8)
Reduce consumption	Reduce pangolin consumption	1.4 (5)
	Alternative sources of food	39.4 (145)
Change behavior	Law enforcement	32.1 (118)
	Continual awareness-raising	5.2 (19)
Habitat protection	Collaborative management of forest	7.3 (27)
	Protect pangolin habitat	35.9 (132)
Increase population	Establish a pangolin breeding initiative	<1 (3)

Discussion

We set out to understand the LEK and traditional uses of pangolins around the Deng-Deng and Mpem et Djim National Parks, Cameroon, and asked communities about pangolin conservation activities. We show that working with local communities can provide useful information for pangolin conservation and management efforts within protected areas. This LEK-based approach has enabled us to collect data on the potential trends in pangolin population size in the area as perceived by the local residents given their life experiences, in a setting where people rely on bushmeat (which often includes pangolins) as a source of food. The data also provided insights into pangolin ecology, local utilization of pangolins other than for meat, and the opinion of local people towards potential conservation activities, which are all essential to consider for effective conservation and collaborative management. We show that black-bellied pangolin is frequently grouped with white-bellied pangolin verbally as *petit pangolin* in French in the study areas. However, the two species could be distinguished morphologically, and local beliefs differed in regard to the two species. Respondents reported that giant pangolins were commonly found in savannah burrows, while the white-bellied pangolins were often seen in the forest, crossing logs and trees. The black-bellied pangolins were reportedly sighted on rattan palms (*Raphia* spp.) in both forest and savannah swamp habitats. Respondents more frequently reported low population size of giant and black-bellied pangolins in DDNP than in MDNP, while the perception of the white-bellied pangolin population was mixed. The people living around these parks had good knowledge of pangolins and did not report widespread or consistent use of pangolins for traditional medicine or other non-consumptive uses. Some people reported use of scales for increasing agricultural yields and as protection against bad spirits, and people reported that it was unlucky to encounter a black-bellied pangolin in the day. Overall, our results are therefore relevant to local conservation stakeholders, and should be considered for the management of wildlife in the study area.

Knowledge of Pangolins

Younger respondents aged between 25 and 35 years old recognized giant pangolins the most among those surveyed. Increased recognition may be the result of past participation in awareness-raising and education campaigns in the younger generations. In Cameroon, the giant pangolin has been protected by law (Class A—highest level of protection) since 1994 and this classification has led to several awareness campaigns throughout its range. Nash et al. (2016) suggested young people are often targeted for their interest in wildlife and conservation. Identification of black-bellied pangolin —mostly accurately done by old respondents was low amongst local people in our study, supporting its population decline over the time (Ingram et al. 2019c). Difficulties with identifying the black-bellied pangolin were observed in other parts of Cameroon (Ichu et al. 2017) and the Republic of Congo (Swiacká 2019). This could be associated with the similar size of the two species and their ecological requirements. Furthermore, the black-bellied pangolin is mostly arboreal and its elusive behavior (likely spending most of its time in the forest canopy) might lead to rare encounters. In comparison, the white-bellied pangolin is semi-arboreal and therefore people may be more likely to observe them while walking through the forest. Confirming the presence of black-bellied pangolin is challenging, but Ichu et al. (2017) found a carcass in Campo Ma'an National Park forest zone during a transect-based survey and have not detected this species using camera-trap. Moreover, recent camera-trap data from DDNP and MDNP recorded no evidence of black-bellied pangolin (Difouo

Fopa 2020; Simo Talla et al. in press). Recently, a black-bellied pangolin carcass was found on the Nyong-ékélé divisional road located approximately 200 km from the Mpem et Djim National Park (Clinton Factheu, personal communication, March 2020). At present, other than the parks being located within the distribution maps for the black-bellied pangolin (Ingram et al. 2019c), no other published records are available that confirm the presence of this species within the parks. Ingram et al. (2019b) suggested testing whether arboreal camera-traps could be used to monitor black-bellied pangolins given the difficulties with using ground-based camera-trap placement due to the species' near total arboreal lifestyle. LEK-based data is sometimes considered inaccurate in the overlapping range of the black-bellied and white-bellied pangolin (Swiacká 2019; Willcox et al. 2019); nevertheless, our survey has shown that cultural beliefs of wildlife may be useful factors to consider in determining possible species presence, and in distinguishing between species that are called the same locally, such as the white-bellied and black-bellied pangolins, in some cases.

Specific Location of Pangolins in the Forest and Savannah

Giant pangolins were reported in both forest and savannah habitat, and have been sighted in and around burrows, fallen dead trees, termite mounds, and swamps, which corroborates Nixon et al. (2019). In the savannah, local people reported sightings at burrows, which is likely because they are a) more conspicuous in savannah habitat, and b) because the soil substrate is suitable for creating burrows, either dug by the pangolin itself or by the aardvark (*Orycteropus afer*) (Kingdon and Hoffman 2013). The burrow locations and presence of giant pangolins have been confirmed by a recent camera-trap survey targeted at burrows and ground feeding sites in the savannah area (Simo Talla et al. in press). The giant pangolins reportedly seen in markets and villages, despite the species scarcity, were based only on pangolin body parts (e.g., tail, legs) prepared as bushmeat for local consumption, rather than the entire body of living or dead individuals.

The white-bellied pangolin was mainly reported from several forest locations, particularly by younger adult respondents who were more likely to be engaged in hunting activities and farmers who farms' activities near forest or savannah increase their encounter rate with this species. In the forest, white-bellied pangolins were sighted walking on the ground, on lianas, and in swamp habitat, which confirms observations from previous studies (Kingdon and Hoffman 2013; Pietersen et al. 2019). Respondents also stated that white-bellied pangolins use fallen trees as pathways across the forest, and that hunters place snares on these logs specifically. The white-bellied pangolin reportedly seen most recently by hunters might be due to their increasing frequency of hunt justify by the increasing international demands for pangolin scales (IUCN 2019), during the last years.

Local people reported that black-bellied pangolins had been seen near rivers and swamps, supporting habitat preferences suggested by Kingdon (1997) and Gaubert (2011). The presence of black-bellied pangolins has been reported in farmlands described to be agricultural areas of former lowland rainforests in the southeast of Nigeria (Pietersen et al. 2019), though it is uncertain if they were present in remnant palm swamps in these degraded landscapes.

Traditional Medicine and Cultural Use

The communities surrounding DDNP and MDNP mostly did not report the use of pangolins for traditional medicine, although scales are sometimes collected when pangolins are captured for bushmeat. The use of fresh pangolin scales for agricultural yield improvement was widespread and had not been recorded before; this belief is a traditional knowledge heritage transfer across generations. One person who is originally from near the Nigerian border and who has settled in the area stated that fresh pangolin scales were used as talismans against evil spirits, which has also been reported in other pangolin range states, such as Nepal (Kaspal 2010) and Ghana (Boakye et al. 2015). While use of pangolin scales for traditional medicine is very low in these communities, the presence of beliefs from other communities may affect pangolin scale use in the future.

Perception of Pangolin Population and Extinction Risk

Giant and black-bellied pangolins were observed by communities in a more distant time and least frequently compared to the white-bellied pangolin, which is similar to results reported in other parts of Cameroon (Ichu et al. 2017) and in the Republic of Congo (Swiacká 2019). Given that the giant pangolin is a burrowing species thought to occur at low densities (Kingdon and Hoffman 2013), this makes them difficult to observe and record using common wildlife survey approaches (Nash et al. 2016). Concerning the black-bellied pangolin, their predominantly arboreal lifestyle in the canopy, low density, and occurrence in swamp habitats might mean that they are rarely observed by residents in these protected areas. The patterns of observation and perceived rarity are also reflected in hunting records from across Central Africa, where white-bellied pangolins are the most commonly caught (Ingram et al. 2018). Furthermore, white-bellied pangolins are thought to occur at higher densities than the other pangolin species (Willcox et al. 2019) and its semi-arboreal lifestyle presumably increases the rate at which white-bellied pangolins are encountered.

Both giant and black-bellied pangolins were perceived to have low population sizes by local communities around DDNP and MDNP, which is similar to that reported by Ichu et al. (2017). It is difficult to interpret the mixed responses of the perceived population status of white-bellied pangolins, where, in both parks, the responses were largely split between low and high. This may be due to the fact that white-bellied pangolins are still seen frequently and recently in the area, but perhaps less often than respondents saw them in the past. It could also be that some villages are surrounded by more favorable habitat for white-bellied pangolins, which may increase their encounter rate.

Around both Deng-Deng and Mpem et Djim National Parks, people considered that pangolins could be at risk of disappearing if protection strategies are not improved. The reasons given for these perceptions are that pangolin populations are low in these areas and that there is pervasive hunting. In contrast, our survey has shown that some local people considered that pangolins are not at risk of extinction because the prohibition of hunting and the park's creation has decreased hunting pressure.

Local Perspectives on the Law and Law Enforcement

Despite most people being aware of the legislation banning hunting and trade of pangolins, a few respondents questioned the need for further protection of pangolins. The level of sensitization widely observed amongst people around the national parks might be a result of forestry control officers (wildlife protection authorities) who frequently conducted awareness-raising campaigns, although we did not measure this. While we found a reasonably high level of agreement towards law enforcement activities, it is unlikely that those who had been arrested were in our sample. Furthermore, this question may have resulted in some level of social desirability bias, whereby respondents may have provided answers that are more socially acceptable or to please the interviewer, particularly for sensitive questions (Grimm 2010).

The communities have suggested strategies for pangolin conservation in their areas which focus principally on managing the trade of pangolins, which has also been suggested by van Vliet and Mbazza (2011) as a way to reduce unsustainable bushmeat harvesting to supply urban markets. Other common suggestions were to provide alternative sources of food, change behavior through law enforcement, and protect pangolin habitat. However, research suggests that some communities may not be motivated to conserve wildlife on which they rely as a primary source of animal protein because they do not have formal rights to benefit from wildlife (Wilkie et al. 2016). In contrast, local people may want to preserve their wildlife from the increasing market demand from towns, reducing availability of meat for local consumption, but may lack the means to do so (Wilkie et al. 2016). This study highlights the ethical aspects of potential conservation activities given that people rely on the consumption of wild meat due to lack of alternatives and the hunting and trading of wild meat as a source of income.

Conclusion and Recommendations

Overall, our results support the notion that LEK can be used to contribute towards increased understanding of pangolin status and threats. Given our results, it is evident that 1) long-term investment and effective management of protected areas will be important for maintaining pangolin populations; and 2) that the needs of local communities need to be considered in conservation action planning. We recommend that governmental and non-governmental organizations explore the feasibility and development of 1) equitable and sustainable management of hunting, and 2) small-scale sustainable farming (such as grasscutters [*Thryonomys swinderianus*]) as an alternative source of protein, income, and employment for local people to reduce hunting pressure. Improvement of local living conditions and employment opportunities may also facilitate the implementation of conservation strategies. We recommend that LEK-based surveys could be used across the sub-region to contribute to understanding of pangolin presence and distribution. Particularly, future research effort should focus on identifying suitable methods to accurately detect the presence and abundance of black-bellied pangolin. Furthermore, targeted surveys of traditional medicine practitioners are needed to better establish whether pangolins are used in traditional medicine across Central Africa. Finally, we recommend the development of educational campaigns focusing on the importance of pangolins and their conservation towards increased survival in the wild, but that the effectiveness of any such effort be fully evaluated and ideally work in collaboration with local communities.

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SHORT COMMUNICATION

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Ant and termite prey of the giant pangolin *Smutsia gigantea* Illiger, 1815 in forest–savannah mosaics of Cameroon

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1 | INTRODUCTION

Pangolins (Pholidoda: Manidae) primarily feed on ants and termites (Ashokkumar et al., 2017; Lee et al., 2017; Pietersen et al., 2016). They consume large amounts of ants and termites with up to 200,000 ants observed being eaten during a single meal (Shi & Wang, 1985 cited by Durojaye & Sodeinde, 2014). The diet of Temminck's ground pangolin (*Smutsia temminckii* Smuts 1832) is the most studied of the four African pangolin species (Coulson, 1989; Kingdon et al., 2013; Pietersen et al., 2016; Swart et al., 1999). Data on pangolin diets are typically derived from scat (Mahmood et al., 2013) and stomach content analyses (Ashokkumar et al., 2017; Coulson, 1989; Gao, 1934; Lee et al., 2017; Minami, 1941) or direct observation of pangolin feeding activities (Pietersen et al., 2016). Temminck's pangolin demonstrates prey selectivity with preferred ant species in both mesic savannah and arid habitats (Coulson, 1989; Jacobsen et al., 1991; Pietersen et al., 2016; Swart, 1992). Diet composition and feeding ecology studies for West and Central African pangolin species—giant pangolin (*S.* [*Manis*] *gigantea*), white-bellied pangolin (*Phataginus tricuspis* (Rafinesque 1821)) and black-bellied pangolin (*Phataginus tetradactyla* (Linnaeus 1766))—remain limited.

The giant pangolin is the largest and heaviest pangolin species. The species is listed as Endangered on the IUCN Red List (IUCN, 2019). It is largely solitary and nocturnal (Bräutigam et al., 1994). The giant pangolin occurs in primary and secondary rainforest forest, savannah and forest–savannah mosaic habitats of Central and West Africa where soils are suitable to search ground dwelling preys (Nixon et al., 2019). It has been reported to feed predominantly on five termite genera, including *Macrotermes*, *Cubitermes*, *Apicotermes*, *Protermes* and *Pseudacanthotermes*, and two ant genera, *Palthothyreus* and *Anomma* (Kingdon, 1972; Nixon et al., 2019). Eleven ant species was also recorded previously as part of the giant pangolins diet (see Bequaert, 1922, cited by Hoffmann et al., 2019). The specific prey species and their relative proportion consumed are not described. Here, we identify and quantify ant and termite species found in stomach content and scat of giant pangolins from an ecotone of Cameroon and compare to the community and abundance profile of cursorial ants of this area to evaluate prey selectivity.

2 | STUDY AREA

The survey was conducted in Mpem et Djim National Park (MDNP) (Figure 1). Mpem et Djim National Park (5°–5°20' N/ 11°30'–12° E; 976 km^2; average altitude of 640 m) is located in the Central Region of Cameroon in the Mbam and Kim Division. The protected area is located in a forest–savannah transition (ecotone) with a mosaic of forest habitats and large block of forests (Dames & Moore, 1999). This park is characterised by classic Guinean climate with four seasons annually; the mean annual rainfall ranges between 1,800 and 2,000 mm per year, while the annual temperature averages 22–29°C

(Tsalefac et al., 2003). Both park vegetation formations are forest and savannah (Figure 1) with several habitat types including mosaic of closed-canopy and open-canopy secondary forests, woodland and grassland savannahs, and gallery forests.

3 | SURVEY METHODS

3.1 | Giant pangolin stomach content and scat analysis

During a community survey in the villages surrounding Mpem et Djim National Park (Difouo et al., 2020), we found a dead juvenile giant pangolin. The Ministry of Forestry and Wildlife (MINFOF) provided a research permit N°0805 that allowed stomach contents of the pangolin to be examined. The stomach content was collected and stored in 90% ethanol and, just prior to analysis, was soaked in fresh water and dried for 10 min on blotting paper following protocol from Mahmood et al. (2013).

One fresh scat sample (estimated as < 24 hr old) was collected in the Mpem et Djim grassland savannah. We assume the scat belonged to an adult giant pangolin because: (a) its large dry weight (120.1 g) precludes all small-size myrmecophagous, other pangolin species and juvenile giant pangolin and the scat appeared different in shape (fusiform) and length (>8 cm) from that described for an aardvark (*Orycteropus afer* Pallas 1766) scat (Chame, 2003); (b) our local guides expressed confidence the scat was from giant pangolin and not an aardvark; (c) camera-trap images from the burrow captured only giant pangolins utilising the burrow and no aardvark (Simo *et al.* in prep); and (d) the relatively close similarity of the prey species composition between the purported scat and the giant pangolin stomach content (see Results). The scat sample (*n* = 1) was collected and stored in a plastic Ziploc bag prior to analysis following previously published methods (Mahmood et al., 2013).

3.2 | Species and genera identification

Following Lee et al. (2017), insects found were sorted into morphospecies based on external morphological characteristics of entire individuals and fragments, including heads and thorax that are strongly keratinised. Ant morphospecies groups were identified using the dichotomous keys

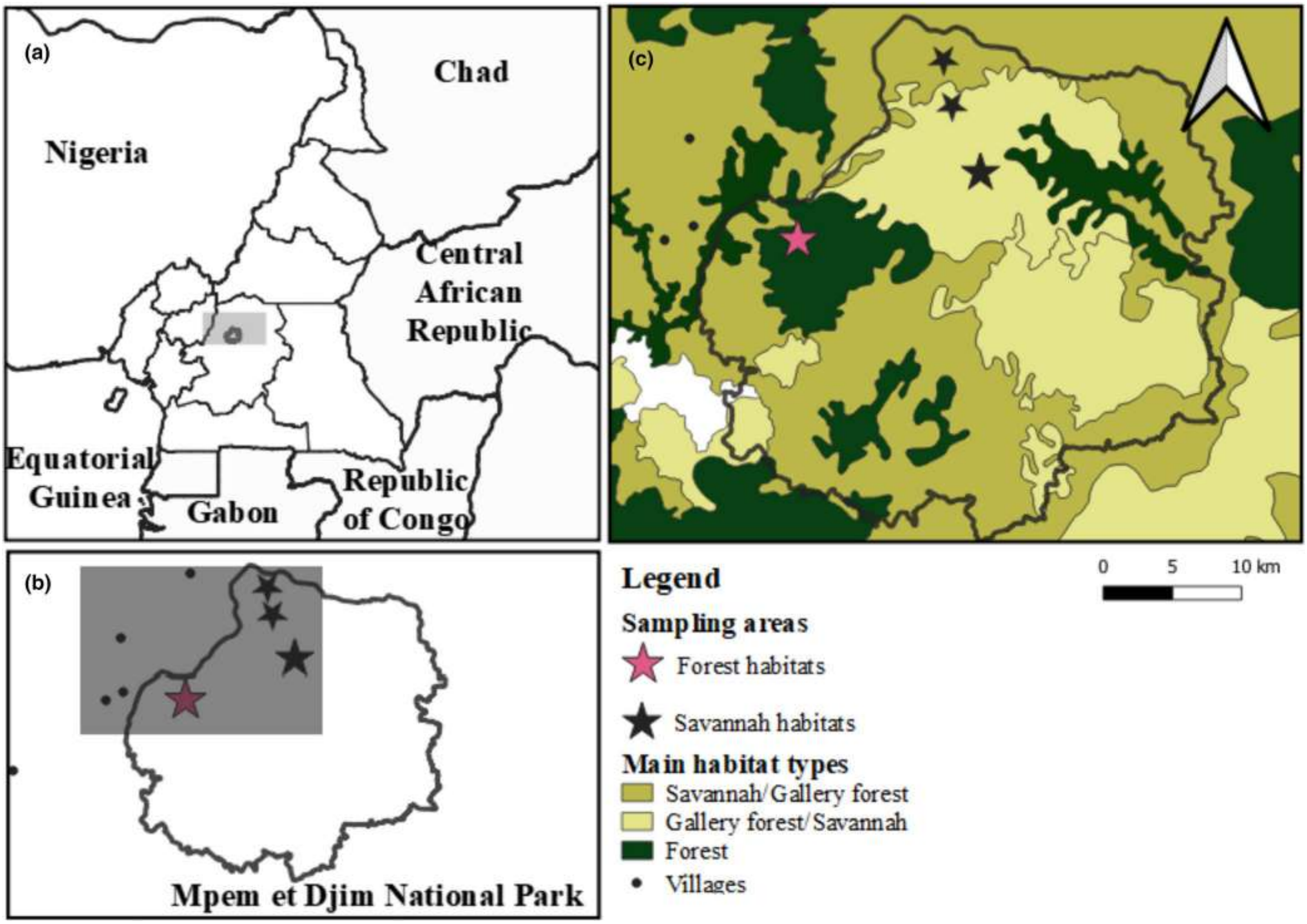

FIGURE 1 Location of Mpem et Djim National Park in the Central Region of Cameroon (a), showing the sampling sites (the stars and black dots) and the main habitat types of the parks (b, c). (source: National Institute of Cartography INC 2012 modified)

in Hölldobler and Wilson (1990), Bolton (1994), and the African Ants systematic database (www.antbase.org). The morphometry of the head and position of the eye on the head among the ant species were used to identify them to species level based on Bolton (1994). Termites were identified based on soldier castes, identified to genus and species, where possible, using appropriate dichotomous keys (Bouillon & Mathot, 1965; Emerson et al., 1928; Ruelle, 1970; Sands, 1965). Specific richness and relative abundance of ants and termites were recorded. Only heads were used as counting unit to prevent errors arising from repeated counting of body fragments. The ant prey species selectivity of the scat and stomach content samples was evaluated by the equation of Manly and colleagues (1993).

4 | RESULTS

4.1 | Ant prey

The juvenile giant pangolin stomach content yielded 1,027 ants (71% of insects recorded; Table 1) comprising nine species. Large ant species predominated, mostly *Camponotus brutus* Forel 1886 (515 individuals, 35%; Table 1) and *Palthothyreus tarsatus* (Fabricius 1798) (240 individuals, 17%). The faecal sample had 3,127 ants (88% of insects recorded), belonging to eight ant species. Large and medium-sized ant species were common, such as *Polyrhachis militaris* Fabricius 1781 (2,171 individuals, 61%; Table 1) and the larger *C. brutus* (538 individuals, 15%). Differences in the composition of the faecal and stomach content samples may simply reflect each pangolin's latest feeding event, rather than individual or age-related preferences. In both, relatively large ant species were most common in the two pangolin's diet as sampled here, namely *C. brutus* and *P. tarsatus*.

The giant pangolin stomach content and scat samples suggest that both pangolin individuals had fed on similar species (six common species representing more than 55% of their diets). Despite their similar composition of species (see Tables 1 and 2), the stomach content did not closely match that found in the scat sample in terms of relative abundance. *Polyrhachis militaris* represented 61% of ants recorded in the pangolin scat compared to 0.5% in the pangolin stomach contents, where *C. brutus* dominated (35%). This may simply reflect the ant species each individual most recently fed on. We compared the giant pangolin stomach and scat content ant communities with the ant communities from each habitat of MDNP. The ant *P. militaris* was primarily collected in grassland savannah (GS) and woodland savannah (WS), while *C. brutus* was most abundant in near-primary forest (NPF) and secondary forest (SF) (Table 1).

4.2 | Termite prey

Termite prey were less than 30% of the total invertebrates recorded in both the scat and the stomach content. The stomach content

TABLE 1 Absolute and relative abundance (RA) and prey selectivity index ($\dot{W}$) for ants between the stomach ($n = 1$) content and scat ($n = 1$) of two different individuals of giant pangolin

	GP-Scat (Adult)		GP-Stomach (Juvenile)				
Ant species	# Ind (%)	Selectivity index ($\dot{W}$)	# Ind (%)	Selectivity index ($\dot{W}$)	Body Avg. length (mm)	RA	Habitat
Camponotus brutus	538 (15)	34.3^{***}	515 (35)	80.66^{***}	15.64 ± 0.64	0.44	NPF
Camponotus flavomaginatus	120 (3)	1.41^{*}	147 (10)	4.24^{**}	9.23 ± 0.52	2.39	SF
Camponotus maculatus	-	-	22 (2)	0.54^{*}	12. 0 ± 0.35	2.79	SF
Cataulacus wessi	150 (4)	421^{***}	-	-	7. 27 ± 1.72	0.01	NPF
Odontomachus troglodytes	66 (2)	0.58	2 (<1)	0.04	10. 50 ± 1.92	3.17	NPF
Palthothyreus tarsatus	7 (<1)	0.07	240 (17)	5.93^{**}	15.55 ± 0.78	2.79	NPF
Polyrhachis laboriosa (F. Smith)	-	-	27 (2)	-	5.38 ± 1.47	-	-
Polyrhachis militaris	2,171 (61)	82.27^{***}	8 (1)	0.74^{*}	6. 27 ± 1.72	0.74	GS, WS
Tetramorium aculeatum	4 (<1)	0.01	-	-	2.17 ± 0.23	8.34	NPF
Pheidole sp.1	-	-	2 (<1)	0.03	2.38 ± 0.44	5.57	NPF
Pheidole sp.2	71 (2)	0.29	63 (4)	0.63^{*}	2.12 ± 0.22	6.94	NPF
Total	3,127 (88)		1,026 (71)				

Note: Average length (mean ± standard error (SE)) of ant body and relative abundance of each ant species per habitat type sampled in the MDNP (see Difouo et al., in prep). The grey colour in rows denotes the importance of the species in the diet composition of pangolin; Habitat type codes are GF, Gallery forest, NPF, near-primary forest, WS, Woodland savannah, SI, Saltworks, GS, Grassland savannah, Sw, Swamp, SF, Secondary forest. Dashed cells denote where information was not provided.

*Lower selectivity.

**Higher prey selectivity.

***Denotes a highest prey selectivity.

TABLE 2 Relative abundance (RA) for termites between the stomach ($n = 1$) content and scat ($n = 1$) of two different individuals of giant pangolin

Termite species	GP-Scat (Adult)	GP-Stomach (Juvenile)	Body Av. length (mm)
	Number of individuals (%)		
Ancistrotermes crucifer	-	6 (<1)	2.01 ± 0.01
Cubitermes sp.	-	13 (<1)	7.31 ± 0.12
Macrotermes bellicosus	74 (2)	89 (6)	14.34 ± 0.42
Macrotermes lilljeborgi	7 (<1)	0	16.7 ± 0.56
Pseudacanthotermes militaris	312 (9)	313 (22)	10.05 ± 0.12
Macrotermes sp.	46 (1)	2 (<1)	-
Termitidae sp.	-	2 (<1)	-
Total	439 (12)	425 (29)	

Note: Average length of termites (mean ± *SE*). The grey shading denotes the two most abundant taxa sampled and dashed cells where information was not provided.

yielded 423 termites (29% of insects recorded) comprising six termite species (Table 2). The scat had 439 termites (12% of insects recorded) comprising four species. *Pseudacanthotermes militaris* Hagen 1858 was the most abundant termite species in both pangolins diet composition (313 [22%] of invertebrates recorded in stomach content and 312 [9%] of invertebrates recorded in scat) followed by *Macrotermes bellicosus* (Smeathman 1781) (89 individuals [6%] in the stomach contents and 74 individuals [2%] in the scat; Table 2). Both termite species are the largest species sampled in the scat, stomach contents and from habitats in the protected area (see Difouo et al., in prep). The most abundant termite species fed upon by both giant pangolins, *P. militaris*, was sampled most in savannah habitats.

5 | DISCUSSION

Although based on initial and limited data, our survey confirms that giant pangolins eat ants and suggests they prefer relatively large ants (>15 mm length) and, in general, feed less on small species despite their greater abundance. The two giant pangolins sampled fed on eight to nine ant species, respectively, with eleven ant species in total in their collective samples similar to Bequaert (1922). Pietersen and colleagues (2016) recorded five species in Temminck's pangolin diet and Swart and colleagues (1999) recorded fifteen. *Camponotus brutus* and *Palthothyreus. tarsatus* were the most abundant ant species in the juvenile giant pangolin's stomach, while *Polyrhachis militaris* and *C. brutus* predominated in the adult pangolin's scat. Again, this difference may simply reflect their latest feeding events. *Palthothyreus* recorded in this survey were mentioned by Kingdon et al. (2013), and *Tetramorium*, *Camponotus*, *Polyrhachis* and *Pheidole* by Bequaert (1922) as part of the giant pangolins diet, while other genera recorded here are not previously recorded. None of ant species recorded was common to the giant pangolins diet examined in previous studies except *Tetramorium aculeatum* (Mayr1). Variation in individual preferences, and spatial and seasonal availability of prey may account, in part, for differences in prey species observed among studies (Swart et al., 1999).

The primary ant prey species of the giant pangolins, namely *Camponotus brutus* (within the stomach of the juvenile pangolin) and *Polyrhachis militaris* (within the scat of the adult pangolin), constituted < 1% of the overall species composition (i.e. number of species recorded in cursorial ant surveys) of the surveyed area (Difouo et al., in prep), although making up 35% and 60% of ants consumed, respectively. This suggests that the giant pangolins preferentially feed on certain prey rather than feeding on the most abundant ant species. Similar behaviour is reported for Temmincks' pangolin (Pietersen et al., 2016; Swart et al., 1999) which favours *Anoplolepis custodiens* (Smith 1858). Larger ants appear to be preferred by giant pangolin, which may increase their foraging efficiency, in terms of time, energy and nutrient value (Swart et al., 1999). The nutritional value of ants increases with larger body size, greater population density and larger nest structure (Swart et al., 1999). We examined an adult pangolin scat and stomach content from a juvenile pangolin; it remains uncertain if juvenile giant pangolins forage in same ways as the adults as has been observed in the Temmincks' pangolin diet (Pietersen et al., 2016).

The surveyed giant pangolins consumed larger termite species (>10 mm in length) and, in general, do not feed much on smaller termites despite their greater occurrence. Among the 53 termite species recorded in MDNP (Difouo et al., in prep), four and six termite species were identified in the scat and stomach contents, respectively. The termite species found in both stomach and scat samples are different to those found in previous studies, which focused on different pangolin species (Pietersen et al., 2016; Swart et al., 1999). Among the prey species recorded and being eaten by giant pangolin here, the genera *Macrotermes*, *Pseudacanthotermes* and *Cubitermes* were previously mentioned by Kingdon and colleagues (2013) and Nixon and colleagues (2019). *Pseudacanthotermes militaris*, the most abundant termite species in both scat and stomach samples, has similarly larger body size as the termite species recorded by Swart and colleagues (1999) and are larger than the species recorded by Pietersen and colleagues (2016) for the Temminck's pangolin. Such as for ants, giant pangolin may favour eating larger termite species for increased foraging efficiency (Swart et al., 1999). Termites represent less than 30% of the examined giant pangolin diets, while ants were up to 80% of the insects recorded. Pangolins may favour ants over termites (Coulson, 1989; Pietersen et al., 2016; Swart et al., 1999). It remains uncertain if termites are eaten by giant pangolin for compensatory nutrients or antidiarrhoeal role as suggested for other mammal species (Deblauwe, 2009).

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CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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RESEARCH ARTICLE

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Diversity patterns of ants and termites in forest-savanna mosaic habitats in two protected areas of Cameroon

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Abstract

Knowledge of ant and termite distribution and ecology is limited for transitional ecosystems in Central Africa. As ants and termites are the primary food for several insectivorous mammals, conservation strategies of threatened species can be strengthened with information on their key food resources. We investigated the ant and termite diversity of two protected areas located in a forest-savanna transition zone in central Cameroon: Mpem et Djim National Park (MDNP) and Deng-Deng National Park (DDNP). Ants and termites were collected along 100 line transects using pitfall and bait traps and hand-sampling during major dry and rainy seasons in seven habitat types. Overall, 14,093 ant individuals representing 108 species, 29 genera, and six subfamilies were recorded. Myrmicinae was the most speciose subfamily in DDNP, while Formicinae dominated in MDNP. The most speciose genus was *Crematogaster* in both parks. *Tapinoma melanocephalum* and *Pheidole* sp. 3 were the most common species recorded in MDNP and DDNP respectively. Ant species richness was highest in near primary forest in DDNP, while richness was greater in the secondary forest of MDNP. Ant communities were more diversified in DDNP than in MDNP. In MDNP, the ant species richness and diversity were highest in the secondary forest and lowest in saltworks, while DDNP near primary forest species richness was highest and swamps lowest. A total of 89 species of termite representing 33 genera and nine subfamilies were recorded from a sample of 56,798 individuals. Termite species richness was similar at DDNP and MDNP. Macrotermitinae was the most common subfamily in both protected areas. The most species-rich termite genus was *Isognathotermes* in both parks. *Macrotermes amplus* in DDNP and *Reticulitermes* sp. in MDNP respectively, were the most commonly sampled termite species. Near primary forest yielded more termite species in DDNP and MDNP than in other habitat types. Termites and ants' communities were more species-rich and diversified in relatively closed-canopy and low-disturbed forest habitats than in savanna and flooded habitats.

KEYWORDS
ants, Cameroon, diversity, forest-savanna habitat, Formicidae, termites, Termitoidae

Résumé

La connaissance de la distribution et de l'écologie des fourmis et des termites est limitée pour les écosystèmes de transition en Afrique Centrale. Les fourmis et les termites étant la principale source de nourriture de plusieurs mammifères insectivores, les stratégies de conservation des espèces menacées peuvent être renforcées grâce aux informations sur leurs principales ressources alimentaires. Nous avons étudié la diversité des fourmis et des termites de deux aires protégées situées dans une zone de transition entre la forêt et la savane au centre du Cameroun : le Parc national de Mpem et Djim (PNMD) et le Parc national de Deng-Deng (PNDD). Les fourmis et les termites ont été collectés le long de 100 transects linéaires à l'aide de pièges à fosse, de pièges à appâts et d'un échantillonnage manuel pendant les principales saisons sèches et pluvieuses dans sept types d'habitats. Au total, 14 093 fourmis représentant 108 espèces, 29 genres et six sous-familles ont été recensées. Myrmicinae était la sous-famille la plus riche en espèces dans le PNDD, tandis que Formicinae dominait dans le PNMD. Le genre le plus riche en espèces était *Crematogaster* dans les deux parcs. *Tapinoma melanocephalum* et *Pheidole* sp. 3 étaient les espèces les plus courantes recensées dans le PNMD et le PNDD respectivement. La richesse en espèces de fourmis était la plus élevée dans la forêt quasi vierge du PNDD, tandis que la richesse était plus importante dans la forêt secondaire du PNMD. Les communautés de fourmis étaient plus diversifiées dans le PNDD que dans le PNMD. Dans le PNMD, la richesse et la diversité des espèces de fourmis étaient les plus élevées dans la forêt secondaire et les plus faibles dans les salines, tandis que la richesse en espèces de la forêt quasi vierge du PNDD était la plus élevée et plus faible dans les marais. Un total de 89 espèces de termites représentant 33 genres et neuf sous-familles ont été enregistrées à partir d'un échantillon de 56 798 individus. La richesse en espèces des termites était pareille dans le PNDD et le PNMD. Macrotermitinae était la sous-famille la plus courante dans les deux aires protégées. Le genre de termites le plus riche en espèces était *Isognathotermes* dans les deux parcs. *Macrotermes amplus* dans le PNDD et *Reticulitermes* sp. dans le PNMD respectivement, étaient les espèces de termites les plus fréquemment échantillonnées. La forêt quasi vierge a révélé plus d'espèces de termites dans le PNDD et le PNMD que dans les autres types d'habitats. Les communautés de termites et de fourmis étaient plus riches en espèces et plus diversifiées dans les habitats forestiers à canopée relativement fermée et peu perturbés que dans les habitats de savane et les habitats inondés.

1 | INTRODUCTION

Ants (Hymenoptera: Formicidae) and termites (Blattodea: Termitoidae) constitute major contributors to invertebrate biomass in Earth's terrestrial ecosystems (Hölldobler & Wilson, 1990; Luke et al., 2014). They have diverse ecological functions in different ecosystems around the world (Eggleton et al., 1996; Hölldobler & Wilson, 1994; Jones & Eggleton, 2000; Majer, 1994; Morrison, 1996). Ants and termites are the most species-rich and ecologically diverse groups of social insects (Lach et al., 2010). In tropical forests, ant and termite communities are generally affected by habitat heterogeneity and resource availability (Tadu et al., 2013; Watt et al., 2002). Many ant and termite species are highly sensitive to habitat structure variation and respond with adaptative strategies to environmental changes that affect arthropods diversity (Adis & Latif, 1996; Alonso & Agosti, 2000; Felicitas et al., 2018; Tchoudjin et al., 2020).

Given that ants and termites play primary role as food and nutrient compensators for 216 mammal species dietary (Deblauwe, 2009; Kingdon & Hoffmann, 2013; Redford, 1987), conservation strategies for threatened species can be strengthened with information on key food resources in these little studied transitional ecosystems (Deblauwe & Dekoninck, 2007; Difouo et al., 2021;Pietersen et al., 2016; Swart et al., 1999). Ants and termites availability as food for pangolins (Pholidota: Manidae) have been surveyed in peri-urban habitats in Asia (Li et al., 2011), mesic savanna, and arid habitats in South Africa (Pietersen et al., 2016; Swart et al., 1999). The ecology of Cameroon's leaf-litter, soil-dwelling, and arboreal nesting ants and termites have been primarily studied in closed-canopy tropical forests, upland, and littoral habitats (Dejean & Bolton, 1995; Dejean et al., 1996, 1997; Fotso et al., 2015, Mbenoun et al., 2021). Abundance and diversity surveys have been undertaken in both natural tropical forests (Deblauwe & Dekoninck, 2007; Dibog et al., 1998; Eggleton et al., 1996) and modified habitats, such as different types of land use management systems (Felicitas et al., 2018; Tadu et al., 2014; Tchoudjin et al., 2020). However, ant and termite ecology remain poorly known in transitional forest-savanna ecosystems in Central Africa.

Here, we compared cursorial and understory ant and termite communities in forest-savanna mosaic habitats of central and eastern Cameroon. Our study aimed to determine the habitat that is favourable for ants and termites diversity in the forest-savanna transition zones. We tested hypotheses about the effect of habitat on the diversity patterns of ants and termites in transitional ecosystems. We answered the following research questions: (1) which vegetation formations harbour high ant and termite species richness in Deng Deng and Mpem et Djim national parks and (2) what is the variation of ants and termites diversity and community structure among national parks and habitats? We predicted that ants and termites are more diversified and species rich in mature forest habitats and parks as they potentially offer more ecotopes, microhabitats, productivity, and resources, (e.g., leaves for shelter, nectar, and leaf litter for foraging) than in immature forest and savanna-type habitats.

2 | METHODS

2.1 | Study areas

The survey was conducted in two national parks in Cameroon, Mpem et Djim National Park (MDNP) and Deng-Deng National Park (DDNP) (Figure 1). MDNP is located in the Central Region of Cameroon in the Mbam and Kim Division (5°–5°20′ N/11°30′–12° E; 976 km^2; average altitude of 640 m). This park is characterised by a Guinean-type climate pattern with four seasons: a long dry season of 4 months (mid-November to mid-March), a short rainy season (mid-March to end of June), a short dry season (from July to August), and a long rainy season (September to mid-November). The mean annual rainfall ranges between 1800 and 2000 mm per year and annual temperature averages 22–29°C (Tsalefac et al., 2003).

Deng-Deng National Park is located in the Eastern Region of Cameroon in the Lom and Djerem Division (5°–5° 25′ N/13°–23° 34′ E, 682 km^2, average altitude of 703 m). DDNP has an equatorial and humid climate with annual rainfall averaging 1500–1600 mm per year (Diangha, 2015). The rainiest months are October (250.96 mm) and September (190.46 mm) while the driest months are January (19.94 mm) and February (24.86 mm). The park has dry and rainy seasons of unequal periods with a mean annual temperature of 23°C (Tsalefac et al., 2003).

Mpem et Djim and Deng-Deng national parks are located in the transition belt of forest-savanna mosaics that transition Central African closed-canopy forests to the northern Soudano-sahelian savannas (Dames & Moore, 1999; Figure 1). Habitat types include near-primary forest (NPF), secondary forest (SF), gallery forest (GF), saltworks (Sl only occurs in MDNP), swamp (Sw), woodland savanna (WS), and grassland savanna (GS) (Nguenang & Dupain, 2002). DDNP has dense forest covering 90.5% (Diangha, 2015) and the forest block in MDNP covers ~43% of the landscape (G. F. Difouo, F. T. Simo, S. Kekeunou, G. T. Ebangue, O. R. Fokou, L. G. Ndoh, I. G. Ichu & D. Olson, unpublished data; Figure 1).

2.2 | Data collection

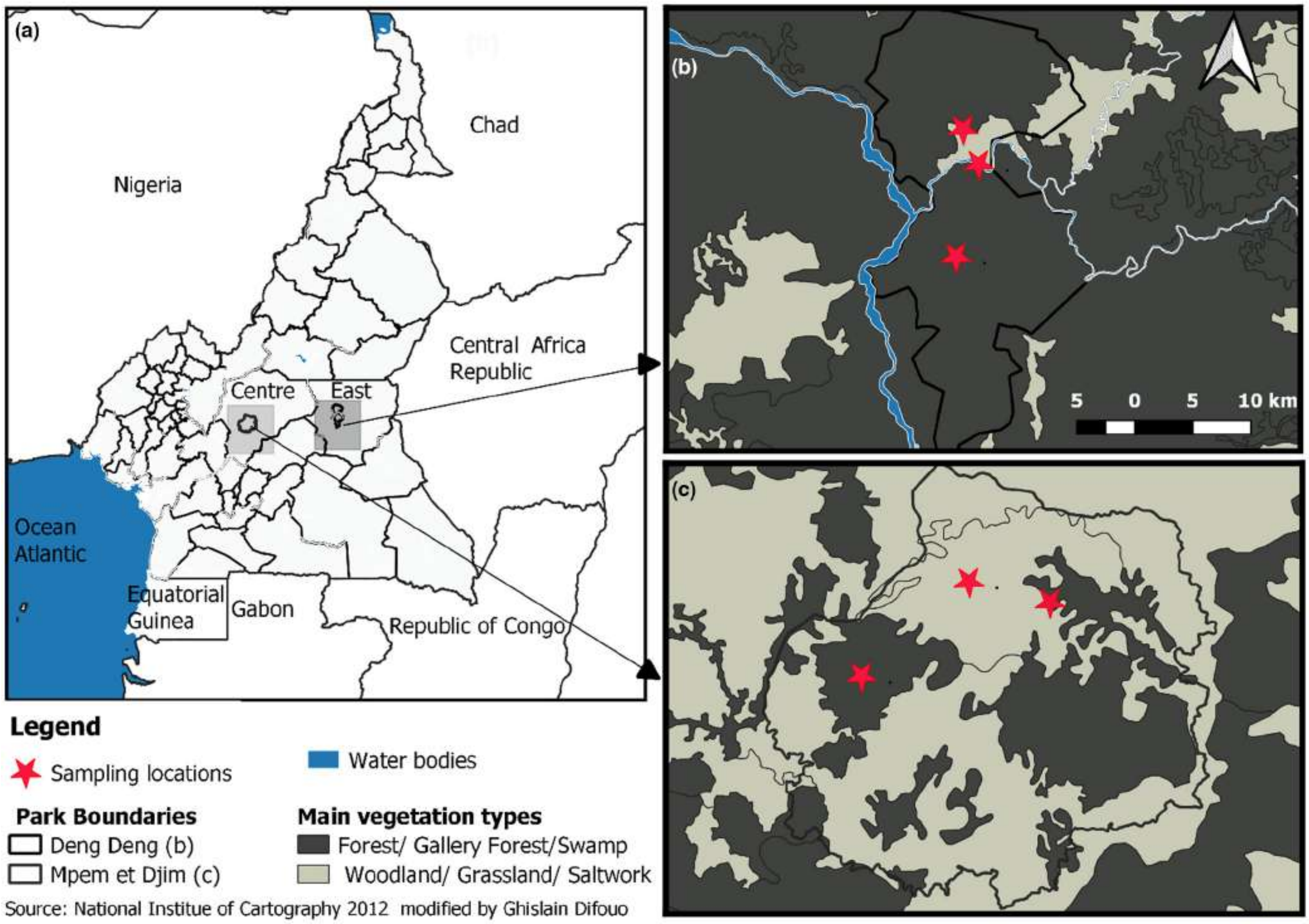
Ant and termite surveys were conducted during the major dry and rainy seasons from April 2018 to April 2020. Sampling was carried out once per season in different habitat types to allow comparison between the insect communities of these habitats. Pitfall traps, bait traps, and hand sampling were used following the protocols adapted from Agosti et al. (2000) and Bestelmeyer et al. (2000). Data from the bait traps contributed to species richness estimates.

2.3 | Pitfall sampling for ants

For ants, all habitats at MDNP were sampled except swamps as they were flooded and at DDNP we sampled all six habitats. Cursorial ants were sampled using pitfall traps on two 100 m line transects established following White and Edwards (2000). Ten pitfall traps (10 cm deep × 10 cm wide) containing soapy water as a catching fluid that is non-toxic to mammals and non-attractive to ants were placed along transects at 10 m intervals following Olson (1991). Each transect of pitfalls was located at least 100 m from another and roughly parallel to the adjacent transects in the same habitat. The pitfalls were collected after 24 h and the ants were stored in vials containing 90% ethanol. A total of 840 pitfall and sardine bait traps were sampled representing 20 pitfalls and 20 baits per habitat type for six habitats sampled during two seasons in two parks along 40 line transects. The savanna zone of MDNP was not sampled during the dry season (representing 16 transects and 160 pitfalls) because of bushfires.

2.4 | Bait and hand sampling of ants

Sardine baits were used as a complementary method to sample diurnal cursorial and foraging ant species (Bestelmeyer et al., 2000). In each habitat type, we deployed two 100 m long transects roughly parallel and 100 m apart each. Ten baits of sardine fish and oil weighing 5 g and arranged on a piece of 10 × 10 cm white paper were placed



Source: National Institue of Cartography 2012 modified by Ghislain Difouo

FIGURE 1 Location of the surveyed sites (MDNP and DDNP) in the Central and Eastern Regions of Cameroon; the location of the stars represents the sampling locations in the main habitat types of the parks. (Source: National Institute of Cartography INC 2012 modified). Some habitat types listed in the method section are included in other which are major habitats (for example swamp habitats are found in secondary forest and near primary forest; gallery forest is included in grassland savanna) and does not appear on the map.

at 10 m intervals along the transect. Baits installed and retrieved after 10 min during the day (between 9:00 AM and 15:00 PM), were rapidly soaked in water to avoid losing individuals. Ants within a 50 cm radius around the baits were captured manually using forceps and used to record the presence of species and not in abundance estimates. In each habitat type and for both pitfall and bait traps methods combined along two transects per habitat, 40 ant samples were collected for 840 samples in six habitats during two seasons in two parks.

2.5 | Hand-sampling for termites

A hand-sampling technique was used to collect termites in microhabitats encountered along 2 km and 2 m wide transect following Abensperg-Traun (1994). This line transect provides a useful method for sampling immobile populations (Anderson et al., 1979). Seven and six habitat types were targeted in MDNP and DDNP, respectively. A total of 60 transects were established in both national parks during major rainy and dry seasons. We focused on ground-level and understory termite feeding or nesting microhabitats (Luke et al., 2014), including (1) epigeal and hypogeal tree active nests, (2) ground termite mounds, (3) leaf litter, (4) dead wood (i.e, decaying tree trunks and twigs), and (5) galleries (i.e., built with soil) on tree trunks up to a height of 2 m (Eggleton & Bignell, 1995). Termites from each microhabitat type were collected manually for 2 min using forceps and stored in vials containing 70% ethanol. In each habitat type, 30 samples of all five termite microhabitats were taken and for all microhabitats examined, 150 samples were collected for a total of 1650 samples in MDNP and 1800 samples in DDNP.

2.6 | Ant and termite species identification

Identification of ant and termite specimens was made under a stereomicroscope at the magnification 20X. Ant species were identified using the dichotomous keys in Hölldobler and Wilson (1990), Bolton (1994), and the African Ants systematic database (www.antbase.org). Termites based on soldier castes were identified to species level when possible, using appropriate dichotomous keys (e.g., Bouillon & Mathot, 1965; Emerson et al., 1928; Krishna et al., 2013; Ruelle, 1970; Sands, 1965) and Termite Systematic Database (http://164.41.140.9/catal/). Voucher specimens were deposited in the reference collection hall of the Laboratory of Zoology, Faculty of Science, University of Yaoundé 1.

2.7 | Data analysis

Because pitfall trap sampling of social insects makes quantitative analyses difficult (García-Martínez et al., 2015; Groc et al., 2014), only presence/absence of species was derived from this data. Likewise, termite abundance was not estimated as the sampling methods employed were not applicable for quantitative analyses (Eggleton & Bignell, 1995).

The total number of species (species richness S or the Hill's zero-order), the co-dominant and simply dominant species was determined using 1st order ($N_1 = e^{H'}$) and second order Hill ($N_2 = \frac{1}{\lambda}$), respectively. Between habitat types, species richness was compared using the Mao's tau rarefaction procedure employing PAST software. The sampling success (SS) was expressed as the ratio ($SS = S._{obs}/TSR \times 100$), where $S._{obs}$ is the observed species richness and TSR is the theoretical species richness (Magurran, 2004). TSR was estimated with the means of four nonparametric incidence-based estimators: the first and second-order Jackknife (Jack1 and Jack2), second-order Chao (Chao2) and ICE (Incidence based Cover Estimator; Magurran & McGill, 2011) employing EstimateS software (version 9.0). Species richness comparisons among habitat types and parks were carried out employing a Chi-square test in R version 4.0.2 (R Core Team, 2020). The frequency of occurrence (F_o) was calculated using the formula $F_o = (f_i/F_t) \times 100$ with f_i representing the occurrence of the *i*th insect species in the sampling units and F_t total number of sampling units (termite microhabitats; pitfalls) examined. Following Dajoz (1982), species, genera and subfamilies were categorised as common ($F_o \geq 50\%$), less common ($25\% \leq F_o \leq 50\%$) and uncommon $F_o \leq 25\%$.

The impact of the studied sites and habitat types on the structure of ant communities was evaluated by plotting the Whittaker rank frequency diagram (Magurran, 2004). We tested the fitting of the model of occurrence distribution to five theoretical models, including Null MacArthur, Preemption, Lognormal, Zipf and Mandelbrot (Krebs, 1999). The best-performing model was the one with the smallest Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC, Mazerolle, 2004). Between national parks, the frequencies of occurrence were compared using the generalised Fisher–Freeman–Halton Test. All *p*-value was interpreted using the two-sided 5% significance level.

Ant communities in both national parks were characterised using Shannon–Weaver Diversity Index (H′), the Maximum Shannon–Weaver Index $H'_{max} = \ln(S)$ with 0 for low diversity assemblages and $H' \leq H'_{max}$ for highly diversified communities. Pielou's Evenness Index (J) ($J = H'/H'_{max}$ with 0 for low evenness assemblages and $\leq J \leq 1$ for absolutely even communities), and Berger–Parker's Dominance Index ($ID = f_{max}/F_t$ with 0 for low dominance and $\leq ID \leq 1$ for absolute dominance) was used. The means of the indices were tested using either Kruskall–Wallis (H) for comparison between habitat types and Wilcoxon (U) tests for national parks because data were not normally distributed.

The dissimilarity between the communities in habitat types was assessed by Ascending Hierarchical Classification based on the Bray–Curtis (Cn) distance. Ward's aggregation method was applied to group the nodes between the communities of the different habitats. Cn = 0 indicates a total similarity between the different communities. Cn, tend towards 1 for the more dissimilar communities. These statistics were determined using PAST 3.20 software (Hammer et al., 2001). The Bray-Curtis index (BC) was used to evaluate similarity between ant and termite communities in habitat types. It is given by the formula:

$$Bc = 1 - Cn \text{ with } Cn = 2JN / (Na + Nb) \tag{1}$$

Na + Nb with Na: total number of individuals from site A; Nb: total number of individuals from sites B; and JN: sum of the abundances of the species found in the two parks. if JN = 0 then Cn = 0, indicates a total lack of similarities between the communities of different habitat types. Cn, tend to 1, the more similar are the communities. The index was generated using EstimateS program.

3 | RESULTS

3.1 | Variation of ant diversity between national parks and habitat types

3.1.1 | Ant species richness

Overall, 14,093 ant-individuals representing *S* = 108 species, 29 genera, and six subfamilies were recorded in both protected areas. In DDNP, 6596 ant-individuals (46.80% of sampled individuals) were recorded, representing *S* = 89 species (82.40% of all species identified), 25 genera (86.05%), and six subfamilies (100%). In MDNP, 7986 individuals (56.66%) were collected comprising *S* = 60 species (55.55%), 19 genera (65.51%), and five subfamilies (83.3%). The ant species richness was significantly highest ($\chi^2 = 5.65$, df = 1, $p < 0.01$) in DDNP with 89 species compared to 60 in MDNP.

In DDNP, Myrmicinae was the most speciose subfamily (41 species, 46.06%), followed by Formicinae (36 species; 40.44%). In MDNP, Formicinae was the most common subfamily (31 species, 51.66%), followed by Myrmicinae (22 species, 36.66%). Ponerinae (with seven species, 6.81%), Dolichoderinae (with four species, 3.70%), and Dorylinae (with two species, 1.81%) were the least common subfamilies. A single species of Cerapachyinae was recorded (0.92%) in DDNP.

The most speciose genera were *Crematogaster* (17 species [58.62%] in DDNP and 10 species [34.48%] in MDNP), followed by *Tetramorium* with 12 species (41.37%) in DDNP and nine species (31.03%) in MDNP. Eighteen genera yield at least two species (6.89%), while 13 genera, namely *Axinidris*, *Cerapachys*, *Tapinoma*, *Paraparatrechina*, *Paratrechina*, *Cardiochondyla*, *Carebera*, *Decamorium*, *Myrmicaria*, *Odontomachus*, *Hypoponera*, *Leptogenis*, and *Loboponera* recorded a single species (3.45%).

The ant species richness was highest ($\chi^2=89.88$, df = 5, $p<0.0001$) in the near primary forest in DDNP (55 species, 50.92%). The secondary forest ant species richness was highest ($\chi^2=41.87$, df = 5, $p<0.0001$) in MDNP (41 species, 37.96%) followed by near primary forest (33 species, 30.55%).

3.2 | Ant species richness estimators and sampling efficacy

More ant species were sampled in MDNP (86.77% of species) than in DDNP (78.05%; see Table 1). The means of four estimators show that 23.13% of ant species are unsampled in MDNP. Most of the ant species in swamps were identified, while almost 50% of species were not sampled in NPF, WS, and SF (Table 1). Overall, ants sampling success mean variation denotes that 38.2% and 18.43% of ant species remain unidentified in NPF and SL. No asymptote was approached on Mao's tau rarefaction curves (Figure 2a).

3.3 | Ant diversity indices

Ant diversity was higher in DDNP ($H'=2.89$; $J=0.76$; $H'_{max}=4.49$) than in MDNP ($H'=2.42$; $J=0.68$; $H'_{max}=4.09$) but not significantly different. Secondary forest ($H'=2.21$ [1.44 ± 0.10, $N=5820$]; $J=0.96$ [0.69 ± 0.03, $N=5820$]) was highly diversified, followed by the WS, NPF, GF, and GS, while the swamp ($H'=0.47$ [0.48 ± 0.08, $N=11$], $J=0.44$ [0.65 ± 0.07, $N=11$]) and saltwork ($H'=1.08$ [0.82 ± 0.29, $N=187$]; $J=0.78$ [0.74 ± 0.06, $N=187$]) habitats were poorly diversified. Overall, ant diversity was higher in all habitat types (Hill index [N_3] was near 0) except in the Swamp ($N_3=1.71$; Table 2) habitat where diversity was significantly lower ($p<0.001$). No species dominated the ant community in the GS, WS, GF, NPF, and SF habitats (Berger–Parker dominance Index; ID < 0.30), except for the swamps (ID = 0.87) and saltworks (ID = 0.52) where a few species dominated.

3.4 | Variation of ant occurrences between parks and habitats

NPF, SF, WS, and GS habitats had the highest simply dominant ant species (at least 16 species) while ant communities in SW and SL were dominated by three species. *Tapinoma melanocephalum* (Fabricius 1793) and *Pheidole* sp.1 were the most common species recorded in MDNP and DDNP's NPF, respectively. *Camponotus acvapimensis* Mayr, 1862, *Crematogaster* (*Sphaerocrema*) sp. 2 and *Odontomachus tryglodytes* Santsch, 1914 dominated the GF (Table 3). *Palthothyreus tarsatus* Fabricius, 1798 was the single most common species in most habitat types except in MDNP's WS where four species were most common: *Camponotus acvapimensis* Mayr, 1862; *Polyrachis militaris* (Fabricius, 1782); *Pheidole magri* Forel, 1910 and *Odontomachus tryglodytes* Santsch, 1914. Ant frequency occurrence was significantly higher in DDNP than in MDNP ($p<0.001$).

3.5 | Ant community structure of parks and habitat types

Ant species occurrences were unevenly distributed in DDNP and MDNP. Figure 3a represents eleven ant species that were commonly sampled (above 50% of events) in both parks. The second section groups the less common ants (up to 28 species in DDNP and 21 in MDNP; between 25% and 50% of events). Most of the ant species (see the third diagram section) were rare (15%–25%). The distribution models of ant species occurrence in both DDNP (AIC = 502.95) and MDNP (AIC = 384.49) fitted the Mandelbrot theoretical model (Table S1 and S2).

Except for the theoretical model of Preemption in WS (AIC = 133.86), the ant occurrences distribution models in GF (AIC = 180.24), GS (AIC = 205.56), NPF (AIC = 263.54), SF (AIC = 251.89) mostly fitted the Mandelbrot theoretical model (Table 4). Ants occurred irregularly in the surveyed habitat types, with eight common species in GF and GS (50% of occurrences; Figure 4a). Seven species were less commonly sampled (with 25%–50% of events) in NPF, whereas almost 50% of species recorded in NPF and SF were rare (5%–25% of occurrence).

3.6 | Similarity of ant communities between habitat types

The highest similarity of ant-specific community composition was observed between GS and GF (Cn = 0.532), followed by NPF and SF (Cn = 0.526) and GF and WS (Cn = 0.434), respectively. While SL and SW (Cn = 0.248 and Cn = 0.05) community structures were the least similar to other communities. Figure 5a shows the dissimilarity between the ant communities in different habitat types.

3.7 | Variation of termite diversity between parks and habitats

3.7.1 | Termite species richness

In both parks, we recorded 56,798 termite individuals representing $S=89$ species, 33 genera, and nine subfamilies. Termitidae was the most speciose family with 86 species (96.62% of all termite species), while Rhinotermitidae had three species (3.37%). Macrotermitinae was the most common subfamily in both protected areas, represented by 29 species (32.58%) in DDNP and 28 species (31.46%) in MDNP, followed by Cubitermitinae (26 species [29.21%] in DDNP and 19 species [21.34%] in MDNP, respectively) and Nasutermitinae with 12 species (13.48%) in MDNP and 10 species (11.23%) in DDNP.

The most species-rich genus in both parks was *Isognathotermes* (13 species [14.60%] in DDNP and 10 species [11.23%] in MDNP), followed by *Microtermes* and *Macrotermes* with seven species (7.86%) in each park. While the least rich genera with a single species included *Coxotermes*, *Sphaerotermes*, *Coptotermes* and others (see Table 4).

A total of 31,625 individual termites were sampled in MDNP, comprising 66 species (74.15%), 24 genera (72.72%), and eight subfamilies. In DDNP, we sampled 25,173 individuals representing 69 species (77.52%), 28 genera (84.85%), and seven subfamilies. Termite species richness was not significantly different ($\chi^2=0.29$, df = 1, $p=0.51$) between both parks.

Near primary forest, with 46 species (49.44% of all species), yielded the highest termite species richness in DDNP, followed by GF (33 species, 33.37%) and SF (30 species, 30.71%). Likewise, in MDNP, NPF had the highest species richness (35 species, 39.33%), followed by the SF (34 species, 38.20%), GF (24 species, 26.97%), then WS and GS (22 species, 24.72%). Termite species' richness was significantly higher in MDNP and DDNP's NPF ($\chi^2=54.43$, df = 5, $p<0.0001$) than in other habitats.

3.7.2 | Termite species richness estimators and sampling success

In DDNP and MDNP, we collected 70.45% and 76.51% of termite species respectively. Sampling success means varied from 49.75% in GS and GF to 91.1% in SF, denoting that 50.25% and 18.9% of termite species were missed in these habitats (Table 1). No asymptote was approached on Mao's tau rarefaction curves (Figure 2b).

3.7.3 | Similarity of termite communities between habitat types

The highest similarity of termite community composition was observed between the GS and WS (Cn = 0.734), followed by NPF and SF (Cn = 0.655), then GS, GF, and WS, GF (Cn = 0.475 and Cn = 0.491), respectively. While SL and SW (Cn = 0.10) community structures were the least similar to others. Figure 5b shows the dissimilarity between the termite communities in different habitat types.

3.7.4 | Occurrence of termite species between parks and habitats

In DDNP, one species recorded was commonly sampled ($F_o \geq 20\%$) in the GF's termite community, namely *Macrotermes amplus* (Sjöstedt, 1899), while *Reticulitermes* sp. was the only common species sampled in MDNP's GF. *Ancistrotermes crucifer* (Sjöstedt, 1897) was the least sampled species in DDNP's GS and MDNP's GF, followed by *Nitiditermes orthognathus* (Emerson, 1928) in MDNP's NPF *Pseudacanthotermes militaris* (Hagen, 1858) in most habitats.

TABLE 1 Ant and termite observed and theoretical species richness as sampling success (%) from species richness estimators by protected areas.

Estimators	DDNP	MDNP
N	6596	7986
S_{obs}	89	60
Ants		
ICE	161 (73.06)	**60 (100)**
Chao 2	146 (76.71)	**60 (100)**
Jack 1	130 (68.46)	**60 (100)**
Jack 2	158 (82.54)	68 (88.23)
Means	129.5 (78.05)	58.75 (86.77)
N	31,625	25,173
S_{obs}	74	66
Termites		
ICE	104 (71.15)	94 (70.21)
Chao 2	94 (78.27)	89 (74.15)
Jack 1	97 (76.23)	91 (72.52)
Jack 2	109 (67.90)	103 (64.07)
Means	**95 (70.45)**	**98 (76.51)**

Note: The numbers in bold denote the higher values of species richness estimators.

Abbreviations: DDNP, Deng Deng National Park; MDNP, Mpem et Dim National Park; N=Sampling size; S_{obs}, Observed Species richness.

The least frequent species in all habitats included *Coxotermes* sp., *Coptotermes sjostedti* Holmgren, 1911, *Lepidotermes goliathi* (Williams, 1954), *Tuberculitermes bycanistes* (Sjöstedt, 1905) and *Pericapritermes urgens* Silvestri, 1914. Termite frequency of occurrence was significantly difference (p = 0.0001) between both parks.

3.7.5 | Termite community structure in different parks and habitat types

Termite species occurrences were unevenly distributed in three groups (see Figure 3b). Firstly, the section above 50% of occurrence (at least 21 species) represents the most commonly sampled termite species. The second diagram section (with 16 species) contain infrequently sampled species (25%–50%). The third section groups the species rarely recorded (17%–25% of occurrence). The distribution models of termite species occurrence in DDNP (AIC = 442.40) and MDNP (AIC = 404.19) fit the Mandelbrot theoretical model (Table S2).

For habitat types, the first section of the Whittaker diagram (13 species; Figure 4b) represents the most commonly sampled species (10% of occurrence) in GF, WS, GS, NPF, and SF. The second section with at least 11 species groups the less common termite species (5%–10%). The third section is the rare species (below 5% of events). Adjustments to the theoretical model show that termite distribution of occurrences fits the McArthur model in all habitat types (Table S2).

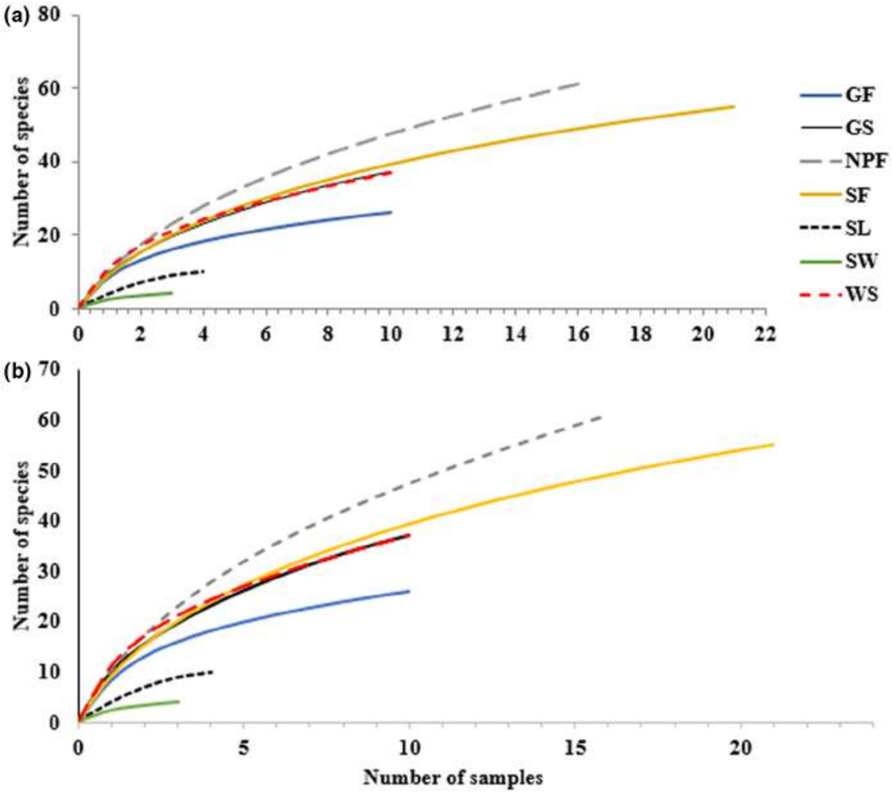


FIGURE 2 Rarefaction curves of ant (a) and termite (b) in the different habitat types of the surveyed areas. GF, Gallery Forest; GS, Grassland Savanna; NPF, Near Primary Forest; SL, Saltworks; SW, Swamp; WS, Woodland Savanna. Saltwork was sampled only in MDNP where it uniquely occurs as well as swamp presents in both parks was sampled only in DDNP.

TABLE 2 Ant diversity indices in each habitat type.

				Habitat types			
	GF	GS	NPF	SF	SL	SW	WS
S_{obs} (N_0)	26	26	70	61	10	4	37
Simpson_1-D	0.78	0.87	0.90	0.92	0.00	0.31	0.90
Shannon_H′	1.88	2.51	2.64	2.74	0.00	0.63	2.63
$H'max = \ln(S_{osR})$	3.26	3.26	4.25	4.11	2.30	1.39	3.61
$N_2 = \frac{1}{\lambda}$	1.28	1.14	1.12	1.09	NA	3.2	1.11
$N_1 = e^{H'}$	6.55	12.33	14.04	15.55	1	1.87	13.89
$N_3 = N_2/N_1$	0.2	0.09	0.08	0.07	NA	1.71	0.08

Note: N_1, Hill's first-order number measure of the number of species that are simply dominant in the community; N_2, Hill's second-order number: measure the most dominant species in the community; Hill's ratio N_3 (N_2/N_1 with $N_2 < N_1$) approaches 1 suggests low species diversity and near zero denotes high species diversity.

Abbreviations: GF, Gallery Forest; GS, Grassland savanna; NPF, near primary forest; SF, Secondary forest; Sl, Saltworks; Sobs, Observed Species richness or zero-order number; Sw, Swamp; WS, Woodland savanna.

4 | DISCUSSION

4.1 | Sampling efficacy of ant and termite communities

For both national parks and habitat types surveyed, the ant and termite species rarefaction curves suggest a good portion of the fauna of each was sampled comparable to other related surveys (Felicitas et al., 2018; Mbenoun et al., 2021; Tadu et al., 2014; Tchoudjin et al., 2020). Near-complete sampling of ants is challenging due to rare, cryptic, and rarely detected species (Gotelli et al., 2011).

4.2 | Variation of ant's communities

4.2.1 | Subfamilies

Myrmicinae was the most commonly sampled and richest subfamily, similar to previous results (e.g., Deblauwe & Dekoninck, 2007; Tchoudjin et al., 2020). This subfamily is the most species rich in most tropical forest ecosystems (Cerda et al., 2012; Lach et al., 2010; Marsh, 1984; Savitha et al., 2008). For example, Myrmicinae were similarly dominant in a survey conducted in the primary closed-canopy forests of the Dja Biosphere Reserve located south of MDNP and DDNP (Deblauwe & Dekoninck, 2007) and in different

TABLE 3 Frequency of occurrence of ant species in each habitat type except swamp and saltwork.

	DDNP					MDNP				
Subfamilies /species	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
Cerapachynae Wheeler, 1902				5.56						
Cerapachys foreli Smith, 1857				5.56						
Dolichoderinae Forel, 1878	90	50	45	50	30	40		94.44	79.17	10
Axinidris murialae Shattuck, 1991			5							
Tapinoma melanocephalum (Fabricius 1793)	80	50	15	44.44	30			94.44	83.34	
Technomyrmex sp.1			30	27.78		20		44.44	41.67	10
Technomyrmex sp.2			25	11.11		20				
Dorylinae Forel, 1893			10	16.67	20			11.11	12.5	
Dorylus braunsi Emery, 1895				5.56	10					
Dorylus nigricans Illiger, 1802			10	11.11	10			11.11	12.5	
Formicinae Wheeler, 1920	100	100	45	38.89	10	80	80	94.44	75	100
Anoplolepis carinata (Emery, 1899)		10						50	50	
Anoplolepis sp.				5.56						
Anoplolepis tenella (Santschi, 1911)								27.78	20.83	
Camponotus vividus (Smith, 1858)									8.33	
Camponotus acvapimensis Mayr, 1862	10	50				50	80	5.56	4.17	80
Camponotus brutus Forel, 1886	90	20	20	27.78	10			16.67	12.5	
Camponotus chrysurus Gertacker, 1871									4.17	
Camponotus congolensis Wheeler, 1922		10								
Camponotus conradti Forel, 1914								5.56	4.17	
Camponotus flavomaginatus Mayr, 1862		10	5					16.67	12.5	
Camponotus foraminosus Forel, 1897			5					11.11	12.5	
Camponotus maculatus Fabricius, 1783	60	60	35	27.78		20	40	16.67	16.67	40
Camponotus pompeius Forel, 1882						40	20	5.56		40
Camponotus sp.1		10								
Camponotus sp.2		10								
Camponotus sp.3		20								
Camponotus sp.4										
Lepisiota capensis (Mayr, 1862)			10						4.17	
Lepisiota foreli (Arnold, 1920)										
Lepisiota guineensis (Mayr)									8.33	
Lepisiota monarda Santshi, 1930		20						27.78	4.17	
Lepisiota n sp Cameroun FK									4.17	
Lepisiota negrisetosa										
Lepisiota nganguela Santshi, 1937		10								
Lepisiota sp.		20	10							
Lepisiota spinosior (Forel, 1930)		10								
Oecophylla longinoda (Latreille, 1802)										20
Oecophylla sp.			5							
Parapartrechina brunnella LaPolla & Cheng, 2010			5							
Paratrechina concinnata								5.56		
Plagiolepis sp.				5.56						
Polyrachis decemdentata André, 1889	10		5	5.56					4.17	
Polyrachis militaris (Fabricius, 1782)		50	10			30	50	5.56	12.5	70

(Continues)

TABLE 3 (Continued)

	DDNP					MDNP				
Subfamilies /species	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
Myrmicinae (Lepeletier de Saint-Fargeau, 1835)	60	80	50	50	30	80	70	88.89	87.5	80
Cardiochondyla wasmani Santschi, 1926			14.29							
Carebera sp.		10	5							
Cataulacus guineensis Smith, 1853										10
Cataulacus weissi Santschi, 1913			5							
Crematogaster concave Emery, 1899			20	11.11						
Crematogaster (*Decacrema*) sp.						10				
Crematogaster (*Oxygyne*) sp.1										
Crematogaster (*Oxygyne*) sp.2							10			
Crematogaster (sphaerocrema) sp.1	10	20				10				30
Crematogaster (sphaerocrema) sp.2						50	40			10
Crematogaster acis			5					5.56	4.17	
Crematogaster bequaerti Forel, 1913		20		16.67						
Crematogaster fauconneti	10								4.17	
Crematogaster melanogaster Emery, 1895			5							
Crematogaster mottazi Santschi, 1928				5.56						
Crematogaster rugosa André, 1895		10								
Crematogaster similis Stitz, 1911		10								
Crematogaster sp.1		20	15	11.11				11.11	4.17	
Crematogaster sp.2		10	5					5.56		
Crematogaster sp.3		10	5	5.56						
Crematogaster sp.4				5.56						
Crematogaster striatula Emery, 1892		20	15	11.11				11.11	4.17	
Crematogaster trautiveini		10	5					5.56		
Crematogaster zavattarii Menozzi, 1926		10	5	5.56						
Decamorium uelense (Santschi, 1923)				5.56						
Monomorium borlei Santschi, 1937					10					
Monomorium mayri Forel, 1902					10					
Monomorium sp.					20					
Myrmicaria opaciventris Emery, 1893				5.56						
Pheidole albidula Santschi, 1928				5.56				27.78	16.67	
Pheidole concinna Wheeler, 1928										
Pheidole magri Forel, 1910						40	50			60
Pheidole megacephala (Fabricius, 1793)	30		10	5.56				38.89	33.33	
Pheidole mentita Santschi, 1914	10						20		4.17	
Pheidole minima Mayr, 1901		10								
Pheidole pulchella Santschi, 1910									12.5	
Pheidole rohani Santschi, 1925								16.67		
Pheidole sp.1	10	50	50	38.89				16.67	25	
Pheidole sp.2	10	10	20	11.11		10				
Pheidole sp.3			15	5.56						
Pheidole speculifera Emery, 1877									12.5	
Tetramorium ataxium Bolton, 1980									4.17	
Tetramorium aculeatum (Mayr, 1886)	20	10	15	11.11	30	40	20	44.44	41.67	

TABLE 3 (Continued)

Subfamilies /species	DDNP					MDNP				
	GF	GS	NPF	SF	WS	GF	GS	NPF	SF	WS
Tetramorium anguilinode Santschi, 1910		10	20	11.11						
Tetramorium bicarinatum (Nylander, 1846)			5							
Tetramorium brevispinosum (Stitz, 1910)			5					16.67	16.67	
Tetramorium coloreum Mayr, 1901			5			10				
Tetramorium gabonense (André, 1892)							10	16.67	12.5	
Tetramorium guineensis (Bernard, 1953)	10	20								
Tetramorium minisculum (Santschi, 1914)				5.56						
Tetramorium monardi (Santschi, 1937)									4.17	
Tetramorium pusillum (Emery, 1895)			5							
Tetramorium rugosum Taylor, 2007			10	5.56	10				4.17	
Tetramorium sp.1			10	5.56				5.56	8.33	
Tetramorium sp.2			5			10				
Tetramorium sp.3				5.56						
Ponerinae (Lepeletier de Saint-Fargeau, 1835)	80	60	40	55.56	30	60	90	83.33	54.17	90
Anochetus nsp Cameroon FK								5.56		
Anochetus bequarti Forel, 1913			10	11.11						
Anochetus sp.					10					
Hypoponera cognata Santshi, 1912						10			4.17	
Leptogenis vindicis Bolton, 1975	10							5.56		
Loboponera sp.								5.56		
Odontomachus tryglodytes Santsch, 1914		20	5	5.56		50	70	5.56	12.5	70
Paltothyreus sjöstedti			5							
Paltothyreus subiridescens (Wheeler, 1922)			5							
Paltothyreus tarsatus Fabricius, 1798	80	60	40	55.56	30	20	50	83.33	54.17	40
Phrynoponera bequaerti Wheeler, 1922									4.17	
Phrynoponera gabonensis André, 1892								5.56		

Abbreviations: DDNP, Deng-Deng National Park; GF, Gallery forest; GS, Grassland savanna; MDNP, Mpem et Djim National Park; NPF, near primary forest; SF, Secondary forest; SI, Saltworks; Sw, Swamp; WS, Woodland savanna.

land use management systems (Tchoudjin et al., 2020) in Cameroon. Formicinae were also speciose rich and commonly recorded, perhaps due to the sampling regime being particularly effective at detecting large-sized cursorial ants (Olson, 1991). The preponderance of Ponerinae is typical for these opportunistic foragers that use many different habitat types (Tadu et al., 2013, 2014).

4.2.2 | Genera

Similar to our result, Deblauwe and Dekoninck (2007) recorded *Tetramorium* as the most species-rich genera recorded in the Dja Biosphere Reserve and different land use management systems (Tchoudjin et al., 2020). Ant species from this genus are very aggressive, and their large numbers often lead to interspecific competitions for space (Tchoudjin et al., 2020). However, *Crematogaster* was the most speciose ant genera in MDNP perhaps due to the fact that this park vegetation is instead a forest-savanna mosaic habitat where forest and savanna habitats alternate. Our result differs from that obtained by Deblauwe and Dekoninck (2007) in the mature moist tropical forest and Tadu et al. (2013, 2014) in disturbed agroforest system in Cameroon. For occurrences, *Camponotus*¸ *Tetramorioum*, *Polyrachis*, *Odontomachus*, *Tapinoma*, and *Pheidole* were the most common genera across all habitats. These genera were similarly common in the forested Dja Biosphere Reserve to the south (Deblauwe & Dekoninck, 2007) and in different land use management systems in Cameroon (Tchoudjin et al., 2020). *Pheidole*, in particular, is a species-rich genus with traits of high aggression and territoriality, contributing to their dominance in the leaf litter (Tchoudjin et al., 2020). *Camponotus* largely forage at night over large areas which may contribute to their high capture rates in pitfalls (Wilson, 1976).

4.2.3 | Species

The most frequently sampled ant species in most habitat types in both MDNP and DDNP is *Palthothyreus tarsatus*, similar to observations of

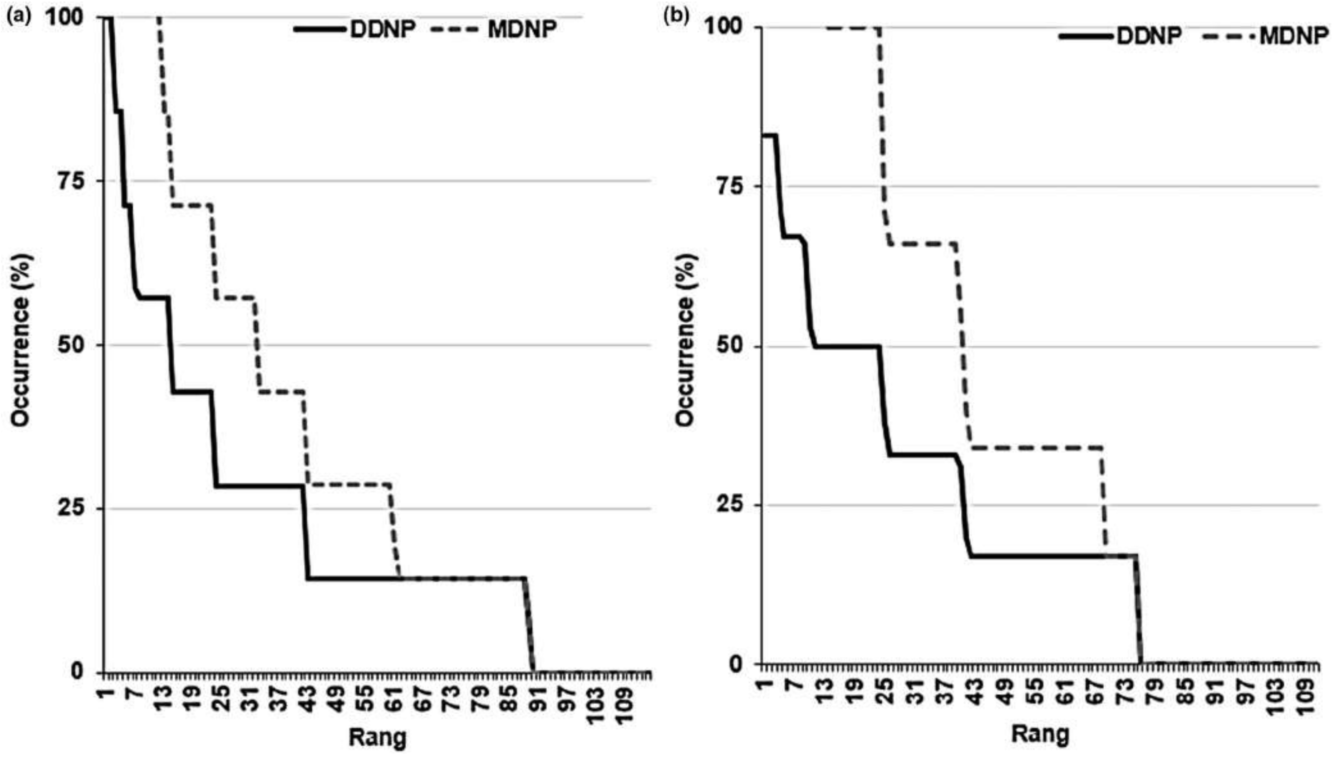


FIGURE 3 Whittaker's rank frequency diagrams showing distribution of ant (a) and termite (b) species occurrences in the communities of Deng Deng National Park (DDNP) and Mpem et Djim National Park (MDNP).

Kalule and Banage (1977). This species forages in groups over large areas which may increase their capture rates (Tchoudjin et al., 2020). In general, the relative abundance of different ant taxa in the samples reflects patterns observed for other Central African forests and savannas (Mbenoun et al., 2021).

4.2.4 | Variation among habitats

Our findings follow the generally observed pattern that relatively intact primary tropical forests have the highest richness and sampling approaches using multiple-capture techniques over longer periods of time to sample more species (Gotelli et al., 2011; Tchoudjin et al., 2020). Overall, ant communities were significantly more diversified in mature and lower-disturbed forests, similar to the result obtained by Lach et al. (2010). Mbenoun et al. (2021) found the same in tropical forests in southern Cameroon. Because they offer more favourable conditions for ants than the savanna habitats. In secondary forests, tree leaves provide a nest and forage sites such as nectar and also some insects captured on the flowers for ants feeding (Tchoudjin et al., 2020). The low ant diversity in swamp habitats is likely due to frequent flooding unfavourable for ground-dwelling and foraging ants (Majer, 1994; Posa et al., 2011). Savanna habitats supported a less rich ant community than closed canopy forests. Savanna ants are not wholly a subset of forest ant communities, rather forming a distinct assemblage. For example, some ant species (e.g., *Tapinoma melanocephalum* and *Pheidole* sp.1) dominate in grassland savanna, gallery forest, and secondary forests. The composition of ant assemblages likely shifts over time in any given locality as habitats transition from secondary to mature forests and forests to savannas and vice versa.

4.3 | Variation of termite's communities

Termite community's assemblages and ecological patterns observed reflect documented trends for Central African forest and savanna environments.

4.3.1 | Families and subfamilies

Termitidae was the dominant termite family in our survey area and Rhinotermitidae species were the least common (similar to Couto et al., 2015 and Felicitas et al., 2018) for other tropical forests. Termitidae dominance may be due to their ability to use cellulose sources other than wood (Inward et al., 2007). Macrotermitinae was the most common subfamily recorded (similar to Eggleton et al., 1995). It is a fungus-growing group of termites widespread in tropical moist forests. Cubitermitinae was also common, their mounds are widespread in savanna. The soldierless termites Apicotermitinae were uncommon in our samples likely because they generally build no nest structures and live in tunnels (Bignell, 2011) which make sampling species of this subfamily challenging unless using soil-sampling methods (Eggleton et al., 1995).

TABLE 4 Frequency of occurrence of termite species sampled across habitat types in the two protected areas.

	DDNP					MDNP				
Sub-families/ species	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
Amitermitinae Kemner 1934		1.25				8.57	4.35	15.25	18.75	11.32
Microcerotermes edentatus Wasmann, 1911						4.76		4.24	3.75	
Microcerotermes fuscotibiallis (Sjöstedt, 1896)						4.76		1.69	2.5	
Microcerotermes pavus (Haviland, 1898)						16.67	2.17		1.25	3.77
Microcerotermes progrediens Silvestri, 1914	16.6	2.17		1.25		16.67	2.17	2.54	3.75	7.55
Microcerotermes silvestrianus Emerson, 1928	16.6	2.17	2.54	3.75		2.38		5.08	7.5	
Microcerotermes sp.1	2.38		5.08	7.5		2.38		1.69		
Apicotermitinae Grassé & Noirot 1955						19.05				1.89
Coxotermes sp.						19.05				1.89
Cubitermitinae Weidner, 1956	37.5	27.5	43.48	31.11	45	19.05	26.09	50.85	43.75	30.19
Crenetermes mixtus Williams, 1962			0.87							
Isognathotermes ugandensis (Fuller, 1923)			3.48	1.11			4.35			1.89
Isognathotermes congoensis (Emerson, 1928)	6.25	2.5	3.48	5.56	15	9.52		9.32	6.25	15.09
Isognathotermes fungifaber (Sjöstedt, 1896)		3.75	1.74			9.52	4.35	5.93		3.77
Isognathotermes gaigei (Emerson, 1928)				2.22			8.7			3.77
Isognathotermes bulbifrons (Sjöstedt, 1924)			6.09	1.11						
Isognathotermes zenkeri (Desneux, 1904)	18.7	1.25	6.09	5.56				7.63	15	
Isognathotermes finitimus (Schmitz, 1916)	6.25	3.75	6.09	4.44	5	2.38		2.54	7.5	
Isognathotermes sp.1				1.11	5	2.38				
Isognathotermes sp.2			0.87							
Polyspathotermes sulcifrons (Wasmann, 1911)			3.48	2.22		2.38	2.17	0.85		7.55
Mirotermes hopes						2.38				
Nitiditermes berghei (Emerson, 1960)	6.25	2.5			15			0.85		
Nitiditermes sankurensis (Wasmann, 1911)			5.22	4.44			2.17	20.34	3.75	
Nitiditermes orthognathus (Emerson, 1928)			0.87						3.75	
Nitiditermes sp.			0.87							
Noditermes lamanianus (Sjöstedt, 1905)			2.61				2.17			
Procubitermes sp.		2.5						1.74		
Procubitermes wasmani (Emerson, 1928)								1.74		
Mucrotermes osborni Emerson, 1960										
Thoracotermes macrothorax			0.87			2.38				

(Continues)

TABLE 4 (Continued)

	DDNP					MDNP				
Sub-families/ species	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
Thoracotermes sp.1										1.89
Thoracotermes sp.2							2.17			
Coptotermitinae Holmgren, 1910										
Coptotermes sjostedti						1.89				
Macrotermitinae Kemner 1934	62.5	60	47.83	60	45	35.71	41.3	28.81	33.75	35.85
Acanthotermes acanthothorax			7.83	5.56						
Allodontotermes sp.1			0.87			2.38				
Ancistrotermes crucifer (Sjöstedt, 1897)	6.25	38.7			20	2.38	8.7	0.85	1.25	5.66
Ancistrotermes sp.		5.01				7.14				
Macrotermes bellicosus (Smeathman, 1781)						7.14	4.35			5.66
Macrotermes lilljeborgi (Sjöstedt, 1896)	6.25		0.87	2.22		2.38		2.54		
Macrotermes mossambicus Hagen, 1853						2.38				
Macrotermes amplus (Sjöstedt, 1899)	25	1.25		3.33	10	2.38		5.93	1.25	
Macrotermes natalensis (Haviland, 1898)		1.25			5	2.38	2.17			
Macrotermes sp.							2.17			
Macrotermes vitrialatus (Sjöstedt, 1899)							2.17			5.66
Microtermes feae Silvestri, 1912			5.22	3.33				0.85		
Microtermes hopes				3.33		2.38				
Microtermes osborni Emerson, 1928	12.5	1.25	6.96	6.67		2.38		4.24	11.25	1.89
Microtermes parvus			2.61	5.56				2.54	5	
Microtermes pusillus Silvestri, 1914		3.75			10				3.75	
Microtermes calvus			0.87			11.9				
Microtermes sp.1			3.48			11.9		5.93	3.75	1.89
Microtermes sp.2			1.74					0.85	3.75	1.89
Microtermes sp.3		1.25		1.11	5			2.54	1.25	
Microtermes sp.4									1.25	
Odontotermes sp.1								0.85	3.75	
Odontotermes lacustris Harris, 1960			0.87			11.9				
Odontotermes mukimbunginis Sjöstedt, 1924			3.48			11.9		5.93	3.75	1.89
Odontotermes stanleyvillensis (Emerson, 1928)			1.74					0.85	3.75	1.89
Protermes hirticeps Sjöstedt, 1924				1.11		7.14		1.69	1.25	1.89

TABLE 4 (Continued)

	DDNP					MDNP				
Sub-families/ species	**GF**	**GS**	**NPF**	**SF**	**WS**	**GF**	**GS**	**NPF**	**SF**	**WS**
Pseudacanthotermes militaris (Hagen, 1858)	6.25	7.5	4.35	2.22	5	7.14	21.74			13.21
Pseudacanthotermes spiniger (Sjöstedt, 1900)	6.25	3.75			5	16.67				
Synacanthotermes acanthothorax (Sjöstedt 1911)	1.11									
Nasutitermitinae Hare 1937		12.5	12.17	10	10	16.67	28.26	2.54	5	20.75
Fulleritermes coatoni Sands, 1965		1.25					2.17			
Fulleritermes sp.										1.89
Fulleritermes tenebricus (Silvestri, 1914)		8.75			10		2.17			
Nasutitermes diabolus (Sjöstedt, 1907)						2.38				1.89
Nasutitermes arborum (Smeathman, 1781)			1.74	3.33		9.52	6.52		2.5	1.89
Nasutitermes fulleri Emerson, 1928			8.7	5.56		11.9	6.52	0.85	2.5	
Nasutitermes santschii						4.76				3.77
Nasutitermes schoutedeni (Sjöstedt, 1924)								1.69		
Trinervitermes bettonianus (Sjöstedt, 1905)		1.25					2.17			
Trinervitermes occidentalis (Sjöstedt, 1904)				1.11			6.52			11.32
Trinervitermes rhodesiensis		1.25				2.38				
Trinervitermes roseri						2.38				
Trinervitermes sp.			1.74			2.38	2.17			
Trinervitermes togoensis				2.38						
Rhinotermitinae Froggatt, 1897			1.74		5	2.38			2.5	
Schedorhinotermes intermidius					5					
Schedorhinotermes putorus (Sjöstedt, 1896)						2.38			2.5	
Schedorhinotermes sp.						2.38				
Reticulitermes sp.			1.74			35.71				
Sphaerotermitinae Engel & Krishna 2004										
Sphaerotermes sphaerothorax (Sjöstedt, 1911)	0.87									
Termitinae Latreille 1802	16.63	1.74	3.33	15	4.74	3.39	6.25	12.41	5.04	3.32
Fastigitermes jucundus (Sjöstedt, 1907)		0.77	3.33				1.25	1.41	1.29	
Furculitermes winifredae Emerson, 1960		3.75			10					
Lepidotermes goliathi	3.75					3.39	3.75	3.75		3.32
Megagnathotermes notandus Silvestri, 1914				5					3.75	
Megagnathotermes sp.1	9.25				2.37			3.75		

(Continues)

TABLE 4 (Continued)

Sub-families/ species	DDNP					MDNP				
	GF	GS	NPF	SF	WS	GF	GS	NPF	SF	WS
Megagnathotermes sp.2		0.77			2.37					
Pericapritermes urgens Silvestri, 1914			0.87							
Promirotermes orthoceps (Emerson, 1928)						2.38			3.75	
Promirotermes sp.	1.74									
Tuberculitermes bycanistes							1.25			

Abbreviations: DDNP, Deng-Deng National Park; GF, Gallery Forest; GS, Grassland savanna; MDNP, Mpem et Djim National Park; NPF, near primary forest; SF, Secondary forest; SL, Saltworks; SW, Swamp; WS, Woodland savanna.

4.3.2 | Genera

The most species-rich genus in both parks was *Isognathotermes* followed by *Microtermes* and *Macrotermes*. Similar results were obtained by Felicitas et al. (2018) who recorded *Microtermes* and *Macrotermes*, as the most dominant genus. *Isognathotermes* is the most frequent genus of Afro-tropical forests termite mounds (Bachelier, 1973) and therefore was among the most sampled. While *Microtermes* are wood-feeder species building galleries on tree trunks and negatively affecting productivity in forest-transition zone (Felicitas et al., 2018).

4.3.3 | Species

The most frequently encountered species in most habitat types were *Ancistrotermes crucifer* and *Pseudacanthotermes militaris*, two wood-feeding termites. These are widespread pests of crops in tropical ecosystems (Bignell, 2011; Felicitas et al., 2018). Predominance of both species may reflect the abundance of dead wood and leaf litter in the surveyed areas (Eggleton et al., 2002).

4.3.4 | Variation among habitats

Termites were most species-rich in relatively closed-canopy and low-disturbance habitats (near primary forest and gallery forest) in both protected areas (see de Paula et al., 2016; Pelissier, 2010). This result reflects previously observed patterns of termite diversity increasing with greater canopy cover (Davies et al., 2003; Dibog et al., 1999; Eggleton et al., 2002). Grassland and woodland savanna habitats communities supported a less rich termite community than near primary and secondary forests. A similar pattern was recorded for ant communities in this study. However, similar functional structure models in termite communities were recorded in all habitat types. A small number of numerically abundant termites were dominant in all sampled habitats suggesting that a small group of termite species may dominate, reflecting early stage of habitat colonization process (Tadu et al., 2014). Our result revealed that species from the genera *Isognathotermes* and *Macrotermes* largely dominate the communities and are distributed in both forest and savanna habitat types and their mounds cover reaches up to 5%–8% in most savanna areas (Okullo & Moe, 2012).

4.4 | Conservation implications and further research

Our initial characterisation of the understory and ground ant and termite faunas provide a foundation for evaluating prey preferences of pangolin species that occur in these national parks in forest-savanna mosaic zones. For example, ants and termites found in giant pangolin (*Smutsia gigantea* Illeger 1815) scat and stomach content samples at the same locality of this study suggest that giant pangolins may

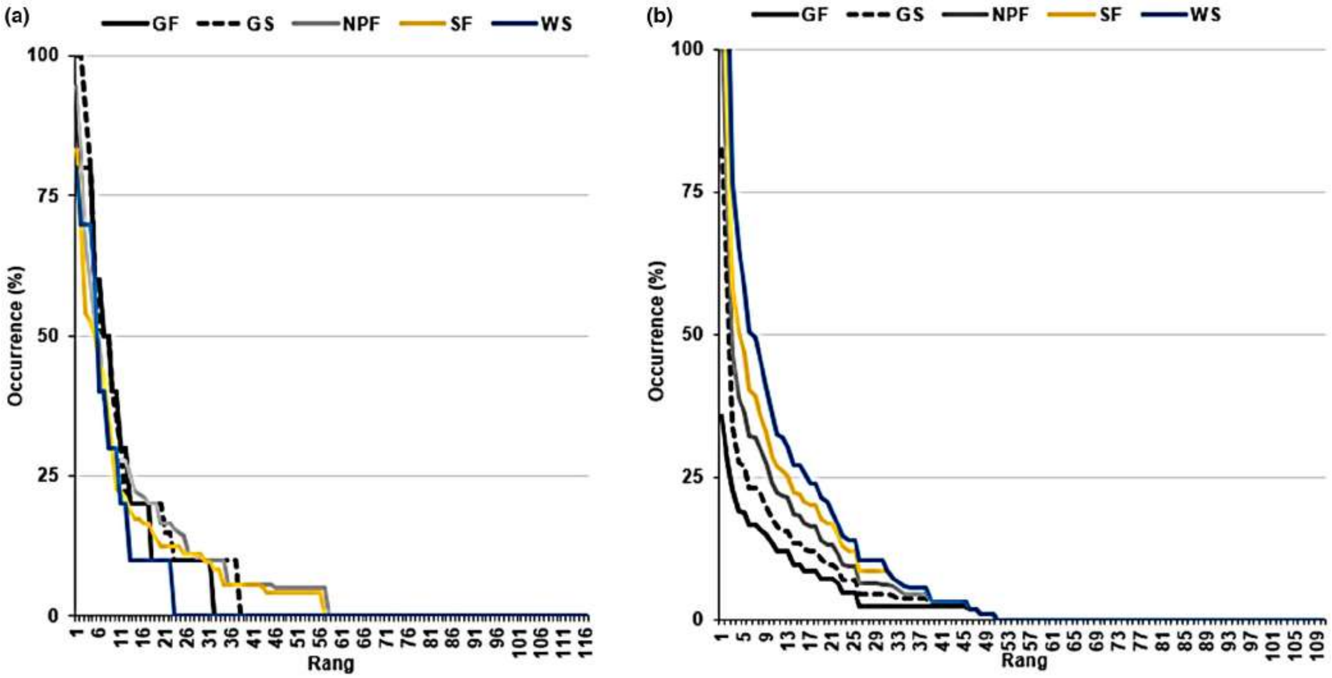


FIGURE 4 Whittaker's rank frequency diagrams showing distribution of ant (a) and termite (b) species occurrences in the communities from different habitat types. Habitat codes are GF, gallery forest; GS, grassland savanna; NPF, near primary forest; SF, secondary forest; SL, saltworks; SW, swamp; WS, woodland savanna. Saltwork was sampled only in MDNP where it uniquely occurs and with swamps were not included in this analysis.

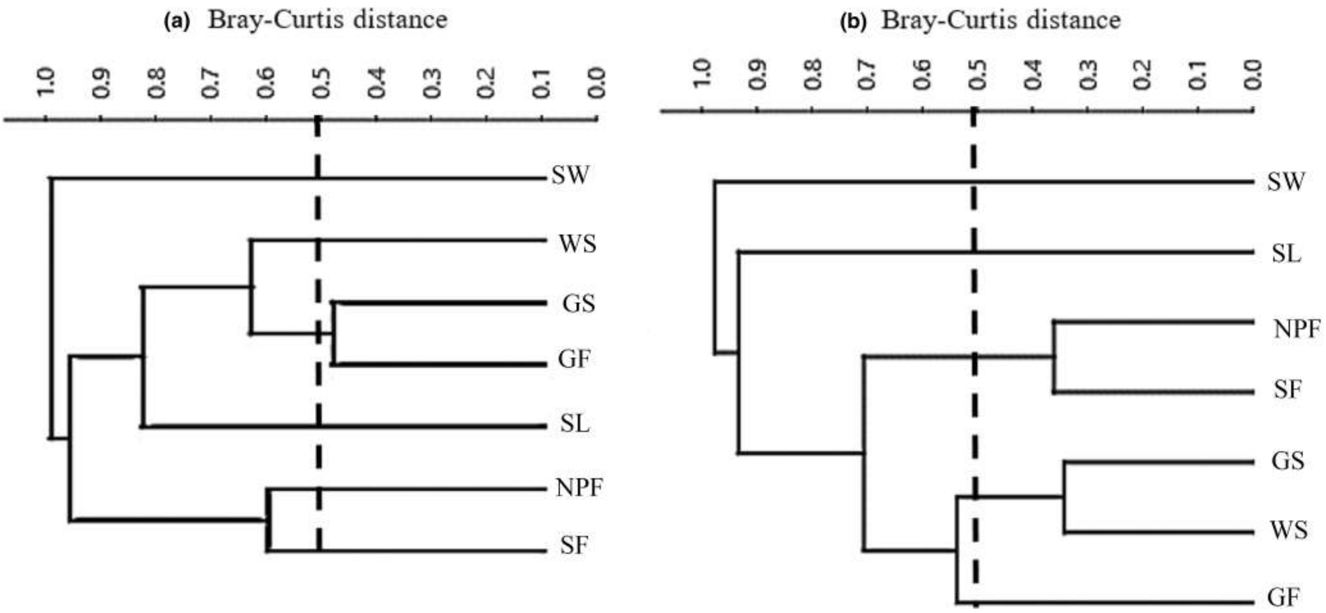


FIGURE 5 Cluster analysis based on Bray–Curtis distance with Ward aggregation method showing dissimilarity in ant (a) and termite (b) communities between habitat types. Bray-Curtis distance (Cn) near 1 indicates a total dissimilarity between the different communities and Cn tend towards 0 for the more similar communities. Habitat codes are GF, gallery forest; GS, grassland savanna; NPF, near primary forest; SF, secondary forest; SL, saltworks; SW, swamp; WS, woodland savanna.

prefer relatively large-sized ants and termites and avoid smaller-sized species (Difouo et al., 2021). A better understanding of the distribution and diversity of potential ant and termite prey of pangolins can inform habitat requirements for their conservation (Difouo et al., 2021).

In our study, more termite species were recorded compared to those from previous pangolin prey assemblage surveys (Pietersen et al., 2016; Swart et al., 1999) in South Africa and another study on termite species (Felicitas et al., 2018) in Cameroon. This may be because we conducted targeted sampling on (1) termite microhabitats increasing the probability of collecting a large number of species and (2) in mature habitats known to be associated with rich species assemblages (Eggleton et al., 2002). However, Eggleton et al. (1995) recorded higher termite species richness in the forestry reserve of Mbalmayo in Cameroon, perhaps due to their sampling technique that facilitated the collection of the subterranean termite family Apicotermitinae. To fully characterise the ant and termite fauna of forest-savanna mosaic zones and understand their functional role, more sampling using more diverse methods (for example, Winkler litter-sifting, nocturnal baiting, soil sampling, canopy sampling for ants) undertaken in all seasons is recommended (see Jones & Eggleton, 2000).

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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