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Population status, threats, and conservation of Preuss's red colobus (*Piliocolobus preussi*)
and other diurnal primates in the Ndokbou forest, Littoral Region Cameroon

Ruth Bowers-Sword

A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Science

Department of Biology

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FACULTY COMMITTEE:

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Dedication

To Emily Mettler,
I will forever strive to carry the adventurous free spirit you embodied in everything you did.
Unimaginably missed.

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Table of Contents

| | |
|--|-----|
| Dedication..... | ii |
| Acknowledgements..... | iii |
| Table of Contents..... | vi |
| List of Tables..... | ix |
| List of Figures..... | xii |
| Abstract..... | xv |
| Chapter 1: Introduction..... | 1 |
| 1.1 Threats to Biodiversity in African Tropical Rainforests | 1 |
| 1.2 Gulf of Guinea Forests | 2 |
| <i>1.2.1 Location and biodiversity</i> | 2 |
| <i>1.2.2 Hunting and the bushmeat trade</i> | 5 |
| <i>1.2.3 Protected areas.....</i> | 6 |
| 1.3 Passive Acoustic Monitoring..... | 7 |
| 1.4 Red Colobus Monkeys..... | 8 |
| <i>1.4.1 Taxonomy & ecology</i> | 8 |
| <i>1.4.2 Threats to red colobus monkeys and their conservation status.....</i> | 9 |
| 1.5 Preuss's Red Colobus | 12 |
| <i>1.5.1 Taxonomy</i> | 12 |
| <i>1.5.2 Ecology</i> | 12 |
| <i>1.5.3 Geographic range.....</i> | 14 |
| <i>1.5.4 Preuss's red colobus in the Ebo-Makombe-Ndokbou forest</i> | 16 |
| <i>1.5.5 Protection status</i> | 16 |
| 1.6 Research Questions and Objectives..... | 18 |
| 1.7 Description of Study Region | 22 |
| <i>1.7.1 Location and topography</i> | 22 |
| <i>1.7.2 Climate</i> | 26 |
| <i>1.7.3 Vegetation</i> | 27 |
| <i>1.7.4 Human populations and activities</i> | 28 |
| 1.8 Primates of the Region | 32 |
| <i>1.8.1 Taxonomy and conservation status</i> | 32 |
| <i>1.8.2 Habitat of primate species.....</i> | 34 |
| <i>1.8.3 Diets of primate species.....</i> | 36 |
| 1.9 Threats to Preuss's red colobus and other diurnal primates in the Ebo-Makombe-Ndokbou forests..... | 38 |
| <i>1.9.1 Hunting and its importance</i> | 38 |
| <i>1.9.2 Hunting methods and bushmeat offtake</i> | 39 |
| <i>1.9.3 Commercial logging concessions and management.....</i> | 41 |
| <i>1.9.4 Logging impacts</i> | 48 |
| 1.10 Thesis Structure | 50 |

| | |
|--|-----|
| Chapter 2: The population status of Preuss's red colobus and other diurnal primates in the Makombe-Ndokbou forests | 52 |
| 2.1 Introduction | 52 |
| 2.2 Methods | 55 |
| 2.2.1 Forest reconnaissance surveys..... | 55 |
| 2.2.2 Data collection | 56 |
| 2.2.3 Data analysis: primate relative abundance | 61 |
| 2.2.4 Data analysis: primate geographic distribution | 64 |
| 2.3 Results | 67 |
| 2.3.1 Primate species richness | 67 |
| 2.3.2 Primate sighting frequency..... | 68 |
| 2.3.3 Primate encounter frequency | 73 |
| 2.3.4 Primate encounter geographic variables: distance to villages and roads . | 78 |
| 2.3.5 Primate encounter geographic variables: terrain ruggedness | 82 |
| 2.3.6 Primate encounter geographic variables: elevation and slope..... | 83 |
| 2.3.7 PCA of primate encounter geographic variables..... | 85 |
| 2.3.8 Primate relative abundance estimates compared to Maokmbe and Korup National Park Forests | 87 |
| 2.4 Discussion..... | 90 |
| 2.4.1 Primate species abundance and distribution | 90 |
| 2.4.2 Primate abundance comparison between Ndokbou-Makombe forests and Korup National Park | 93 |
| Chapter 3: Hunting and logging activity assessments | 94 |
| 3.1 Introduction | 94 |
| 3.2 Methods | 99 |
| 3.2.1 Forest survey data collection and analysis: hunting activity..... | 99 |
| 3.2.2 Passive acoustic monitoring: acoustic sensor configuration | 100 |
| 3.2.3 Passive acoustic monitoring: acoustic sensor deployment | 101 |
| 3.2.4 Passive acoustic monitoring data analysis: gunshot selection review.... | 104 |
| 3.2.5 Passive acoustic monitoring data analysis: gunshot frequency..... | 105 |
| 3.2.6 Passive acoustic monitoring data analysis: gunshot temporal frequency | 106 |
| 3.2.7 Forest survey data collection and analysis: logging activity..... | 107 |
| 3.3 Results | 108 |
| 3.3.1 Hunting encounter frequency | 108 |
| 3.3.2 Hunting encounter geographic variables: distance to villages and roads | 116 |
| 3.3.3 Hunting encounter geographic variables: terrain ruggedness | 118 |
| 3.3.4 Hunting encounter geographic variables: elevation and slope | 120 |
| 3.3.5 Hunting encounter rates compared to Makombe and Korup National Park forests | 121 |
| 3.3.6 Passive acoustic monitoring: gunshot frequency and geographic distribution | 122 |
| 3.3.7 Passive acoustic monitoring: gunshot temporal distribution..... | 127 |
| 3.3.8 Passive acoustic monitoring: gunshot frequency comparison to Korup National Park | 132 |
| 3.3.9 Logging encounter frequency | 134 |
| 3.3.10 Combined hunting and logging encounter frequency and distribution.. | 139 |

| | |
|---|-----|
| 3.4 Discussion..... | 141 |
| 3.4.1 Hunting activity in the Ndokbou forest..... | 141 |
| 3.4.2 Temporal patterns of gun hunting | 144 |
| 3.4.3 Hunting comparisons between forests..... | 145 |
| 3.4.4 Logging activity in the Ndokbou forest | 146 |
| Chapter 4: Conclusions..... | 147 |
| 4.1 Summary of Findings | 147 |
| 4.2 Synergistic Impacts of Logging and Hunting on Primate Abundance | 149 |
| 4.3 Passive Acoustic Monitoring as a Conservation Tool..... | 154 |
| 4.4 Conservation Outlook for the Ebo-Makombe-Ndokbou Forest Block | 155 |
| Appendix I: The total number (“nombre”) and volume (m ³) of each tree species (“Essences”) inventoried by TRC for logging in FMU 00-004 of the Ndokbou forest (Derived from Bureau Veritas Certification, 2012) | 159 |
| References..... | 160 |

List of Tables

| | |
|---|----|
| Table 1.1. The IUCN red list conservation status for all 18 forms of red colobus (<i>Piliocolobus</i> spp.) (IUCN, 2020)..... | 11 |
| Table 1.2. Total human population estimates (total # of individuals) and population densities (persons/km ²) for countries located in Sub-Saharan Central and West Africa as of July 1, 2019 (UN, 2019b)..... | 30 |
| Table 1.3. Diurnal primate species found in the Ebo-Makombe-Ndokbou forest with average male + female body weight (kg) (Linder, 2008; Kingdon, 2015) and species' IUCN conservation status (IUCN, 2020) | 33 |
| Table 1.4. The biomass (kg) of wildlife hunted over the course of 32 weeks within the Ebo forest. Data derived from Fuashi <i>et al.</i> 2019. | 41 |
| Table 2.1. Grid location, survey distance (km), and time parameters for each recce survey conducted in the Ndokbou forest..... | 60 |
| Table 2.2. Recce surveys conducted in 2018 in the Ndokbou forest (data provided by J. Linder) with total survey distances (km) and combined 2018 and 2019 overall survey effort .. | 63 |
| Table 2.3. Primate species' sighting frequencies (groups/km) during 2018 and 2019 surveys with total number of sightings indicated in parentheses | 69 |
| Table 2.4. Overall mean sighting frequencies (groups/km) for each primate species encountered in the Ndokbou forest. Sighting frequency was calculated by combining 2018 and 2019 survey data..... | 70 |
| Table 2.5. Overall mean primate sighting frequency (groups/km) for each grid surveyed during 2019 surveys in the Ndokbou forest..... | 71 |
| Table 2.6. Primate species' encounter frequencies (groups/km) during 2018 and 2019 surveys with total number of encounters indicated in parentheses. Encounter frequency was calculated by combining sighting encounters and vocalization encounters | 73 |
| Table 2.7. Overall mean encounter frequency (groups/km) for each primate species encountered in the Ndokbou forest. Encounter frequency was calculated by combining sighting encounters and vocalization encounters pooled from 2018 and 2019 survey data..... | 75 |
| Table 2.8. Overall mean encounter frequency (groups/km) for each grid surveyed during 2019 surveys in the Ndokbou forest..... | 75 |
| Table 2.9. The total number of <i>P. t. ellioti</i> nest encounters for each 2019 survey grid including total number of individual nests, minimum, maximum, and average nest group size..... | 78 |
| Table 2.10. The minimum, maximum, and average distance (km) for each primate species encountered (direct and indirect encounters) from the nearest main public road found in the Ndokbou forest. Data were combined from 2018 and 2019 recce surveys..... | 80 |
| Table 2.11. The minimum, maximum, and average distance (km) for each primate species encountered (direct and indirect encounters) from the nearest main logging road (inactive) found in the Ndokbou forest. Data were combined from 2018 and 2019 recce surveys..... | 81 |
| Table 2.12. The minimum, maximum, and average distance (km) for each primate species encountered (direct and indirect encounters) from the nearest village found in the Ndokbou forest. Data were combined from 2018 and 2019 recce surveys | 81 |
| Table 2.13. Minimum, maximum, and average Vector Ruggedness Measurement (VRM) values for each primate species encountered in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys | 82 |

| | |
|---|-----|
| Table 2.14. Minimum, maximum, and average Vector Ruggedness Values (VRM) with the incorporation of elevation (m) for each primate species encounter in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys | 83 |
| Table 2.15. Minimum, maximum, and average elevation (m) at which primate species were encountered in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys..... | 84 |
| Table 2.16. Minimum, maximum, and average slope (degrees) at which primate species were encountered in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys..... | 84 |
| Table 2.17. The overall primate encounter frequency (groups/km) compared between the Ndokbou and Makombe forest | 87 |
| Table 2.18. The overall primate sighting frequency (groups/km) compared between the Ndokbou and Makombe forests..... | 87 |
| Table 2.19. The overall primate encounter frequency (sightings and vocalization encounters) (groups/km) for each species of primate compared between the Ndokbou and Makombe forests..... | 88 |
| Table 2.20. Primate sighting frequency (groups/km) compared between two regions of Korup National Park (Linder, 2008), and the Ndokbou and Makombe forests | 89 |
| Table 3.1. The deployment date, retrieval date, total recording time (days), and total recording area (km ²) for each passive acoustic monitoring sensor deployed in the Ndokbou forest. Total recording area is based on the 1.5 km gunshot detection radius for each sensor | 103 |
| Table 3.2. Hunting trail sign encounter rates (signs/km) for each 2019 grid surveyed in the Ndokbou forest | 109 |
| Table 3.3. Hunting sign encounter rate (signs/km) for each 2019 grid surveyed in the Ndokbou forest | 110 |
| Table 3.4. Gun hunting sign (shotgun shells and gunshots heard) encounter rate (signs/km) for each 2019 survey grid..... | 112 |
| Table 3.5. Combined 2018 and 2019 survey data for hunting sign encounter rates (signs/km) for each type of hunting sign. “Misc.” includes indirect human signs such as boot prints, trash, or tree markings | 114 |
| Table 3.6. Minimum, maximum, and average distance (km) to the nearest village that each type of hunting sign was encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys | 117 |
| Table 3.7. Minimum, maximum, and average distance (km) to the nearest main public road that each type of hunting sign was encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys..... | 117 |
| Table 3.8. Minimum, maximum, and average distance (km) to the nearest main logging road that each type of hunting sign was encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys..... | 118 |
| Table 3.9. Minimum, maximum, and average Vector Ruggedness Measure (VRM) values for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys | 119 |
| Table 3.10. Minimum, maximum, and average VE (VRM and elevation) value for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys..... | 119 |
| Table 3.11. Minimum, maximum, and average elevation (m) for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys..... | 120 |

| | |
|--|-----|
| Table 3.12. Minimum, maximum, and average slope (degrees) for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 and 2019 surveys..... | 121 |
| Table 3.13. The overall hunting encounter rate (signs/km) compared between the Ndokbou, Makombe, and Korup National park (Linder, 2008) forests | 122 |
| Table 3.14. The encounter rate (signs/km) of each type of hunting sign compared between Ndokbou, Makombe, and Korup National Park (Linder, 2008) forests. Total number of signs encountered are in parenthesis | 122 |
| Table 3.15. Gunshot frequency (gunshots/day) detected by each passive acoustic sensor located in the Ndokbou forest | 124 |
| Table 3.16. The total number and overall percentage of gunshots recorded during daylight hours and during night hours across all passive acoustic monitoring sensors | 127 |
| Table 3.17. Gunshot frequency (gunshots/day) for each day of the week of passive acoustic monitoring recording in the Ndokbou forest | 128 |
| Table 3.18. Gunshot frequency (gunshots/day) for each week of acoustic monitoring recording during 2019 in the Ndokbou forest..... | 130 |
| Table 3.19. Gunshot frequency (gunshots/day) for each month of acoustic monitoring recording during 2019 in the Ndokbou forest..... | 131 |
| Table 3.20. Logging encounter rate (signs/km) for each 2019 survey grid..... | 135 |
| Table 3.21. Logging encounter rate (signs/km) for each type of logging sign..... | 136 |
| Table 3.22. Encounter rates (encounter/km) for combined hunting and logging signs of each 2019 survey grid in the Ndokbou forest | 139 |

List of Figures

| | |
|--|----|
| Figure 1.1. The Gulf of Guinea rainforest region located between the Niger and Sanaga River with designated protected regions and the Ebo-Makombe-Ndokbou forest block. (Land cover data is derived from MDA BaseVue 2013 land use/land cover (LULC)) | 4 |
| Figure 1.2. Geographic range of all 18 forms of red colobus monkeys (Linder, Cronin, Ting et al. 2020)..... | 9 |
| Figure 1.3. Adult female Preuss's red colobus (<i>Piliocolobus preussi</i>) (Butynski & Kingdon, 2013) | 13 |
| Figure 1.4. Geographic range of Preuss's red colobus (<i>Piliocolobus preussi</i>) (adapted from Linder et al. 2019; Linder, Cronin, Ting et al. 2020)..... | 15 |
| Figure 1.5. The location of the Ebo-Makombe-Ndokbou forest block in relation to Korup National Park and Cross River National Park, Nigeria..... | 24 |
| Figure 1.6. The location of Mt. Sinai and major rivers within the Ebo-Makombe-Ndokbou forest region | 25 |
| Figure 1.7. Monthly precipitation (mm) amounts between 2013 and 2015 for a single site located in the Ebo forest represented by black bars (continuous forest CF-800m) (Ley et al. 2018)..... | 27 |
| Figure 1.8. Locations of villages along the only motorable road bordering the Ebo and Ndokbou forests..... | 31 |
| Figure 1.9. The location of commercial logging Forest Management Units (FMUs), community production forests, and the Azur palm oil plantation located near the Ebo-Makombe-Ndokbou forest block..... | 46 |
| Figure 1.10. Logging FMU 00-004, concession 1029 broken down into designated ~2,500 ha assiette de coupe parcels (parcel boundary data obtained from the Cameroon Ministry of Forestry and Wildlife, https://cmr.forest-atlas.org/map?l=en) | 47 |
| Figure 2.1. Grid, with 4 km x 4 km grid cells (grid cell ID numbers in gray boxes), overlaid on the Ndokbou forest for designating areas of the forest to complete recce surveys | 58 |
| Figure 2.2. The location and GPS track of each recce survey completed in 2019 in grids 3, 10, 19, 20, 26, 27, and 34 (grid numbers indicated in corresponding boxes) in the Ndokbou forest..... | 59 |
| Figure 2.3. The location of recce surveys conducted in the Ndokbou forest in 2018 compared to the recce survey locations conducted for this study in 2019..... | 62 |
| Figure 2.4. Terrain ruggedness analysis using Terrain Rugged Index (TRI) vs. Vector Ruggedness Measure (VRM). In regard to TRI, A (flat terrain) would result in a low TRI value, while B (steep terrain) and C (steep and rugged terrain) would both result in similar TRI values. In regard to VRM, A (flat terrain) and B (steep, smooth terrain) would result in low VRM values and C (steep and rugged terrain) would result in high VRM values. (derived from Sappington et al. 2007)..... | 66 |
| Figure 2.5. The distribution of primate species encounters within each 2019 survey grid with reference to grid numbers in gray boxes..... | 68 |
| Figure 2.6. Geographic distribution of every primate sighting encounter point during 2019 surveys in the Ndokbou forest with reference to grid numbers in gray boxes..... | 71 |
| Figure 2.7. The percentage of each primate species sighted in each 2019 survey grid..... | 72 |
| Figure 2.8. The percentage of each primate species encountered (combined vocalization and sightings encounters) in each 2019 survey grid..... | 76 |
| Figure 2.9. <i>P. t. ellioti</i> nest encounter totals for each 2019 survey grid with reference to survey grid numbers in gray boxes..... | 77 |

| | |
|---|-----|
| Figure 2.10. Geographic distribution of every primate encounter point (sighting and indirect encounters) with <i>P. t. ellioti</i> nest encounters and the location of the <i>P. preussi</i> encounter (Lat: 4.574743°, Long: 10.493658°) during 2019 surveys in the Ndokbou forest with reference to grid numbers in gray boxes..... | 79 |
| Figure 2.11. Principal component analysis (PCA) on primate species encounters using averages of geographic variables encountered in the Ndokbou forest (variable labels: VRM = Vector Ruggedness Measure, VE = VRM and Elevation index, VD = distance to nearest village, Elev = elevation, RD = distance to nearest road) | 86 |
| Figure 3.1. The locations of six acoustic sensors used for acoustic data collection in the Ndokbou forest with reference to 1.5 km detection radius. ARUs 3 and 5 have two different deployment locations indicated as “3.1”, “3.2” and “5.1”, 5.2” | 102 |
| Figure 3.2. Acoustic sensor locations with reference to overlapping detection areas with sensor 3.1 and 5.1 detection areas (numbers in overlap area represent total area km ² of overlap) | 104 |
| Figure 3.3. All hunting signs encountered during 2019 surveys with reference to grid numbers in gray boxes | 109 |
| Figure 3.4. Hunting sign encounter rates (signs/km) of each hunting sign type encountered in each 2019 survey grid..... | 111 |
| Figure 3.5. Locations of gun hunting signs (shotgun shells and gunshots heard) and hunting camps encountered during 2019 surveys with reference to grid numbers in gray boxes | 113 |
| Figure 3.6. Principal component analysis of gun hunting signs on survey grids in the Ndokbou forest from 2019 data. Gun hunting variables: SS = shotgun shells, Gun = gunshots heard, Snare = snare-traps, trail = hunting trails, Camp = hunting camps..... | 115 |
| Figure 3.7. Acoustic sensor location and mean gunshot frequency (gunshots/day) with reference to survey grid numbers..... | 123 |
| Figure 3.8. The geographic distribution of gun hunting pressures identified by gunshot frequency estimates (mean gunshots/day/sensor) from sound data recorded by acoustic sensors compared to the number of gun hunting signs encountered during recce surveys with reference to survey grid numbers in boxes | 125 |
| Figure 3.9. Encounter rates of gun hunting signs (signs/km) for each 2019 survey grid. Numbers above bars indicate the total number of gun hunting signs encountered in each grid | 126 |
| Figure 3.10. Avg. gunshot frequency (gunshots/day) for each acoustic sensor. Numbers above bars indicate the total number of gunshots recorded for each sensor | 126 |
| Figure 3.11. The percentage of total gunshots recorded during daylight hours (06:00 – 18:00) and during night hours (18:01 – 05:59) by passive acoustic monitoring sensors in the Ndokbou forest..... | 127 |
| Figure 3.12. The percentage of total gunshots recorded by passive acoustic monitoring sensors for each day of the week in the Ndokbou forest..... | 129 |
| Figure 3.13. Gunshot frequency (gunshots/day) for each week of acoustic monitoring recording with reference to periods of the rainy and dry season in the Ndokbou forest..... | 131 |
| Figure 3.14. Comparison of percentage of gunshots recorded for each day of the week by passive acoustic monitoring between the Ndokbou forest and Korup National Park (adapted from Astaras et al. 2017; J. Linder pers. comm.) | 133 |
| Figure 3.15. Korup National Park monthly gunshot frequencies in 2014-2015 with reference to the wet season and dry season from passive acoustic monitoring data (adapted from Astaras et al. 2017) | 133 |
| Figure 3.16. Comparison of gunshots/sensor/month recorded by acoustic sensors in Korup National Park and the Ndokbou forest..... | 134 |

| | |
|---|-----|
| Figure 3.17. All logging sign encounters during 2019 surveys in the Ndokbou forest with reference to survey grid numbers in gray boxes | 135 |
| Figure 3.18. Principal component analysis results of PC1 and PC2 using the encounter frequency of all logging signs on survey grids | 137 |
| Figure 3.19. Principle component analysis conducted using the six most influential logging signs on survey grids. Logging signs include tree markings (“Marking”), loading areas (“LA”), logging camps (“camp”), cut stumps (“CS”), cut logs (“CL”), and logging roads (“Road) | 138 |
| Figure 3.20. Principle component analysis using hunting and logging sign encounters in 2019 survey grids. Hunting signs include: Gunshots heard (“Gunshot”), snare traps (“Snare”), hunting trails (“Trail”), hunting camps (“Hunting camp”), and shotgun shells (“SS”). The six most influential logging signs were used, which includes: tree markings (“Marking”), logging camps (“Logging Camp”), cut stumps (“CS”), cut logs (“CL”), and logging roads (“Roads”) | 140 |

Abstract

The Ebo-Makombe-Ndokbou forest block in southwest Cameroon lies within the Gulf of Guinea biodiversity hotspot, characterized by extremely high levels of species richness and endemism, including those of primates. These forests may contain one of the last populations of the Critically Endangered Preuss's red colobus monkey (*Piliocolobus preussi*; PRC), which is found only in southeastern Nigeria and western Cameroon. Gun hunting for bushmeat and habitat loss and degradation from logging and agriculture are the main threats to PRC. The conservation status of PRC and other primates in the Ndokbou forest are largely unknown, with most regional research efforts occurring in the nearby Ebo forest. I assessed the population status of and threats to PRC and other diurnal primates in the Ndokbou forest to inform and improve their protection. I conducted forest reconnaissance surveys to estimate primate abundance and distribution and to assess hunting and logging activities. I also deployed acoustic sensors to assess the spatiotemporal patterns of gun hunting. I compared primate abundance and gun hunting in the Ndokbou forest to those from the protected Korup National Park. Overall primate abundance was less than half of that of Korup NP. Of the nine primate species I encountered in the Ndokbou forest, I heard PRC only once. *Cercopithecus nictitans* was the most abundant species, accounting for 56% of all primate encounters. Recce surveys suggested that gun hunting activity was widespread with no significant variation in geographic distribution. However, acoustic sensors identified higher levels of gun hunting in areas closest to villages and logging roads, while forest surveys failed to show these differences. Mean gunshot frequency, as measured by the acoustic sensors, was 0.46 gunshots/day in the Ndokbou forest compared to 0.55 gunshots/day in Korup NP. Results suggest that logging activities may have facilitated widespread hunting, which has led to the observed low primate abundance for every species. More evidence for the presence of PRC is needed to confirm its presence in Ndokbou, but if they do occur in the Ndokbou forest they are likely restricted to the most remote and rugged areas of the forest with low gun hunting

levels. However, despite impacts from logging and hunting, this forest still contains important endangered primate species. The best hope for their protection likely lies in community-led conservation efforts that address wide-spread hunting levels driven by logging operations.

Chapter 1: Introduction

1.1 Threats to Biodiversity in African Tropical Rainforests

The African tropical rainforest zone contains more than 25% of all African mammals and more than 1800 endemic plant species (N'Guessan et al. 2018). Hunting and human activities that lead to habitat loss and degradation threaten the integrity of these rainforests (N'Guessan et al. 2018; Norris et al. 2010; Aleman et al. 2018).

With increasing human populations, there is an increased demand for natural resources (Brandt et al. 2017; Lambin & Meyfroidt, 2011; Mayaux et al. 2013). As of 2019, Sub-Saharan Africa contained a human population of approximately 1.06 billion individuals and is projected to add an additional 1 billion people by 2050, accounting for 52% of the world's population (UN, 2019a). This will surpass the population of central and southern Asia, effectively making it the most populous region in the world. Subsequently, the demand for agricultural land and other forest products from African tropical forests in particular has resulted in the deforestation of nearly 28% of all African forests since the early 1900's and a loss of 90% of the original rainforest cover (Aleman et al. 2018; N'Guessan et al. 2018).

In addition to this forest loss, an estimated 4 million tons of wildlife are hunted, primarily for meat, from the Congo Basin each year, constituting a critical threat to wildlife in this region (Dobson et al. 2019; Friant et al. 2015; Fa and Brown, 2009; Harrison, 2011). Wild meat, or "bushmeat", is an open access resource and a critical protein source for rural people in central and West Africa (Friant et al. 2015; Fa and Brown, 2009). Urban demand for bushmeat, rising per capita income, and improved hunting methods (i.e., shotguns) have helped catalyze the commercialization of the bushmeat trade, which has become a key source of income for rural people (Fa et al. 2009). Consequently, bushmeat is now supplementing both diets and incomes, transforming a once subsistence-based activity into one that is market-driven and unsustainable for many species (Fa et al. 2003; Bennett et al. 2006; Nasi et al. 2011).

Mechanized logging operations have created increasing road networks, allowing for efficient, easy access into once hard-to-reach areas of the forests for hunting activities. This allows for widespread, efficient hunting practices leading to overall increased levels of hunting and bushmeat offtake (Wilkie et al. 2000; Laurance et al. 2006, 2017). Logging roads and trucks facilitate the transportation of meat from forest to market, thus, promoting the commercialization of the bushmeat trade (Laporte et al. 2007; Poulsen et al. 2009). Logging operations also bring more people into forested regions with previously low human population densities. As the number of people and their income increase so does the demand, trade, and consumption of bushmeat obtained from surrounding catchment areas (Poulsen et al. 2009; Tieghong & Zwolinski, 2009).

Overall, mammals constitute the greatest offtake of bushmeat hunting in the African tropical forest zone (Fa and Brown, 2009). Compared with many species of ungulates and rodents, which typically comprise the majority of bushmeat biomass at many sites, primates are more vulnerable to hunting (Fa and Brown, 2009; Nasi et al. 2011). Due to their conspicuous social groups, relatively slow reproductive rates, and large body size compared with ungulates and rodents, primates often are among the first mammals to decline in abundance in regions with high hunting intensity (Nasi et al. 2011).

Habitat loss from selective logging and agricultural expansion and bushmeat hunting and trade are the leading causes of wildlife population declines in the Gulf of Guinea rainforest region in western Africa, a biodiversity hotspot characterized by exceptionally high levels of species richness and endemism.

1.2 **Gulf of Guinea Forests**

1.2.1 Location and biodiversity

The Gulf of Guinea rain forest region is situated between the Niger River in Nigeria and the Sanaga river in Cameroon, including the continental shelf island of Bioko, Equatorial Guinea

(Oates et al. 2004) (Figure 1.1). Due to the immense variation of geographic features, including the largest river delta in tropical Africa and the largest contiguous forest block of West Africa, this region is characterized by exceptionally high levels of species richness, diversity, and endemism among plants and animals (Oates et al. 2004). However, this region also contains some of the largest concentrations of human populations in Africa. Human activities including hunting for the bushmeat trade is a pervasive threat, affecting even the most strictly managed protected areas including Cross River National Park (Nigeria), Korup National Park (Cameroon), Pico Basilé and the Gran Caldera Scientific Reserve (Bioko).

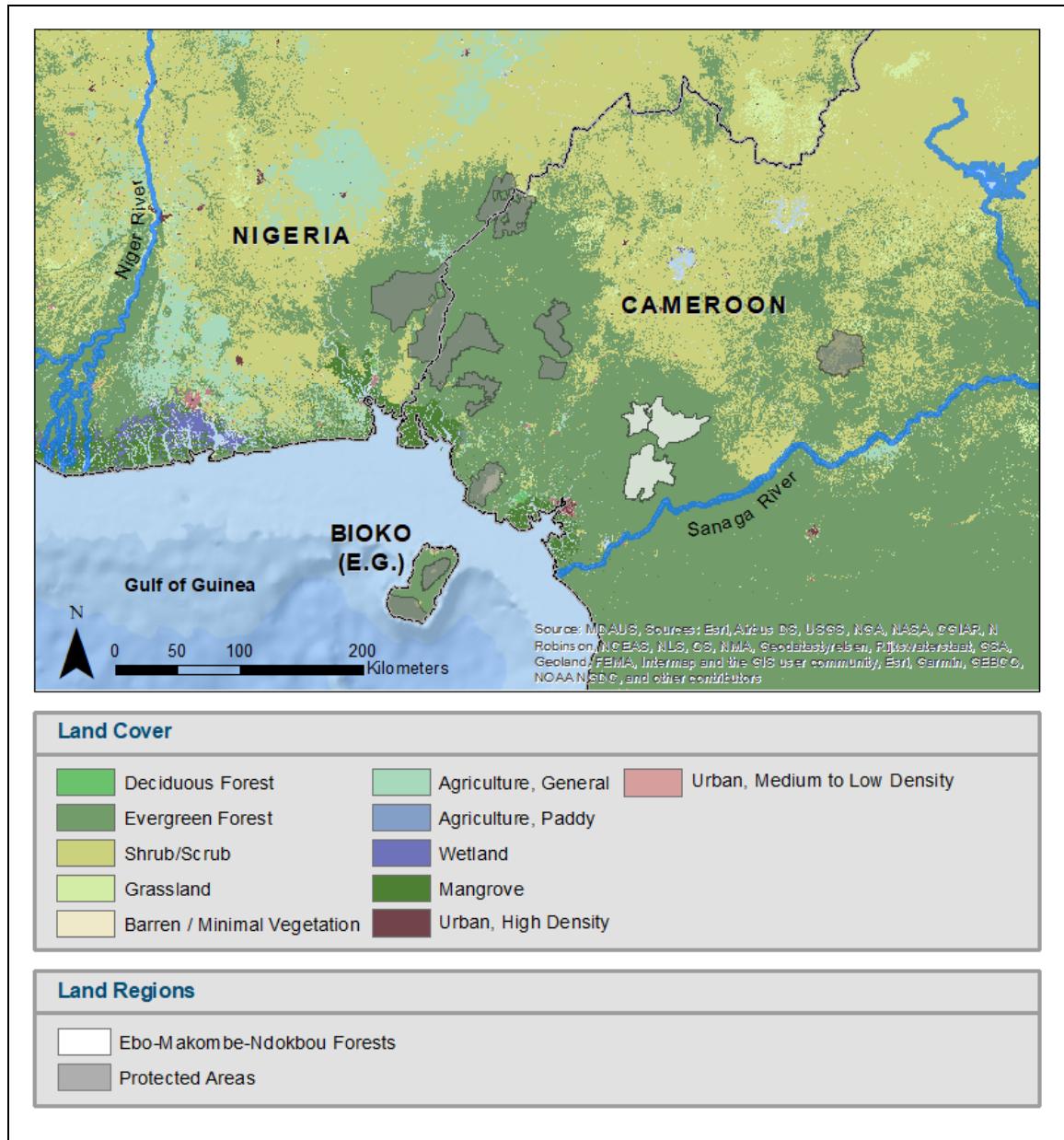


Figure 1.1. The Gulf of Guinea rainforest region located between the Niger and Sanaga River with designated protected regions and the Ebo-Makombe-Ndokbou forest block. (Land cover data is derived from MDA BaseVue 2013 land use/land cover (LULC)).

1.2.2 Hunting and the bushmeat trade

The most recent estimates of bushmeat hunting from 2009 in the Gulf of Guinea region between the Cross and Sanaga rivers of Nigeria and Cameroon approximate an annual offtake of 12,000 tons of terrestrial wildlife (Fa and Brown, 2009). While a significant source of protein comes from bushmeat in rural regions of the Gulf of Guinea, an average of 72% of bushmeat is hunted for profit to supply the bushmeat trade (Cawthorn & Hoffman, 2015). The emergence of bushmeat as an important economic resource has led to unsustainable levels of hunting in the Gulf of Guinea.

Unsustainable hunting is a major contributor to the Earth's sixth mass extinction event currently underway (Ripple et al. 2016). In sub-Saharan Africa alone, over 500 different wildlife species are hunted with mammals constituting the primary source of bushmeat (Ape Alliance, 2006; Fa & Brown, 2009). Primates in particular constitute some of the largest proportions of bushmeat offtake along with large ungulates and rodents (Nasi et al. 2011; Fa et al. 2014; Estrada et al. 2017).

Hunting disproportionately affects long-lived, large species of mammals such as primates. With low intrinsic rates of population increase, these species struggle to recover from drastic population depletions from hunting. Many of these species provide important ecosystem services including seed dispersal, pollination, and herbivory. One study found that in tropical forests experiencing significant mammal defaunation, seed dispersal declined by 25-93% (Kurten, 2013). This inhibits the regeneration of fruiting plants that rely exclusively on mammals for dispersal (Effiom et al. 2013). Ultimately, the loss of wildlife that provide key ecosystem services has profound cascading impacts on food webs and community dynamics, which impacts overall forest community structure and biodiversity.

Unsustainable hunting leading to population declines of wildlife species also impacts rural communities relying on bushmeat as a source of protein (Ripple et al. 2016). Bushmeat supply in the Congo Basin is predicted to drop by 81% by 2050 due to current unsustainable

levels of hunting (Cawthorn & Hoffman, 2015). This may have little effect on urban populations consuming bushmeat as a luxury item, but large declines in bushmeat from unsustainable hunting will disproportionately affect the rural poor relying bushmeat as a source of protein (Ripple et al. 2016). Golden *et al.* (2011) found that the loss of access to bushmeat resulted in a 29% increase in the prevalence of childhood anemia and tripled anemia rates among children in the poorest households. Therefore, loss of wildlife from unsustainable hunting is predicted to lead to severe declines of sources of protein, impacting human health and food security for the Congo Basin's most rural and poorest communities (Brashares et al. 2011; Ripple et al. 2016). Ultimately, the overexploitation of wildlife and the bushmeat trade represent a crisis from both a conservation and food security perspective (Bennett et al. 2016; Ripple et al. 2016).

1.2.3 Protected areas

There are protected areas within the Gulf of Guinea attempting to restrict hunting and habitat loss in order to preserve biodiversity. Protected areas in the Gulf of Guinea that most strictly limit human activities include Cross River National Park (Nigeria), Korup National Park (Cameroon), Bakossi National Park, Pico Basilé National Park (Bioko), and the Gran Caldera Scientific Reserve (Bioko). Korup National Park (KNP) utilizes law enforcement ground patrols and Cross River National Park (CRNP) additionally uses the Spatial Monitoring and Reporting Tool (SMART). SMART is an evidence-based management tool that park officials use to record occurrences and locations of human activities including hunting, illegal logging, and agriculture encroachment. More recently, passive acoustic monitoring has been successfully used in KNP to locate and quantify gun hunting activity and inform the design of anti-poaching patrols (Astaras et al. 2017).

1.3 Passive Acoustic Monitoring

Passive acoustic monitoring (PAM) is a method traditionally used for monitoring wildlife populations and their behaviors, particularly within marine environments (Johnson & Tyack, 2003; Sousa-Lima et al. 2013). In terrestrial environments PAM is most commonly used for the study of bat (Adams et al. 2012; Russo and Voigt, 2016; Sugai et al. 2019) and bird populations (Blumstein et al. 2011; Rempel et al. 2013). However, advances in this technology have allowed widespread application of bioacoustic research in challenging terrestrial habitats (Merchant et al. 2015) to garner ecological and population demographic information on other terrestrial mammals including primates (Heinicke et al. 2015; Kalan et al. 2015, 2016; Crunchant et al. 2020) and forest elephants (Wrege et al. 2012, 2017). Additionally, acoustic monitoring is growing rapidly as a terrestrial conservation tool to assess the impacts of human activities on wildlife populations (Wrege et al. 2017; Deichmann et al. 2017; Sugai et al. 2019).

One rapidly growing conservation benefit of utilizing PAM is its ability to provide an unprecedented level of detail on gun hunting patterns, particularly in regions where this human activity is threatening the survival of rare and threatened species (Astaras et al. 2017). By continuously recording (up to 24 hours/day), sensors can record and store the sounds of gunshots, which can later be analyzed in sound analysis software programs to approximate the spatial and temporal distribution of gun hunting activities (Astaras et al. 2017).

This method of utilizing PAM technology may produce a more accurate measure of gun hunting pressures compared with traditional forest patrol methods as it unbiasedly relies on actual hunting events, by recording gunshots, to assess where and when gun hunting takes place. Traditional forest patrol methods rely on encountering evidence of gun hunting (e.g., spent shotgun shell cartridges, hunters, and hunting camps). However, this method may yield a biased assessment of hunting as hunters can collect and remove hunting evidence and avoid detection by patrolling efforts. Additionally, patrols cannot be continually omnipresent, therefore limiting the

temporal and spatial monitoring extent of gun hunting activities (Plumptre et al. 2014; Tranquilli et al. 2014). PAM can also be used in conjunction with other law enforcement monitoring tools such as SMART to validate patrol-based evidence and improve the ability to design, evaluate, and adapt anti-poaching strategies (Wrege et al. 2017).

Astaras and colleagues (2017) deployed a network of acoustic sensors to elucidate gun hunting activity in Korup National Park, Cameroon (Astaras et al. 2017). They found gun hunting occurred year-round, although it was more frequent during the dry season (November - March). They also determined that gun hunters were most active at night and during the weekdays leading up to the Saturday market day. Acoustic data also detected increased hunting activity over the two-year monitoring period, a pattern that traditional techniques of measuring hunting pressure (i.e., transect surveys) failed to detect. Passive acoustic monitoring in Korup provided unprecedented detail on gun hunting activity.

In addition to using PAM to monitor gun hunting activity and evaluate the effectiveness of conservation strategies (e.g., anti-poaching patrols), PAM can also improve detectability of rare or cryptic animals, especially in dense rain forest environments (Enari et al. 2018; Yan et al. 2019). These kinds of animals may be missed using traditional survey methods (e.g., line transect and reconnaissance surveys). PAM, is thus, a potentially useful tool for also assessing presence/absence of the Critically Endangered Preuss's red colobus monkey.

1.4 Red Colobus Monkeys

1.4.1 Taxonomy & ecology

The taxonomy of colobus monkeys has long been under review with current classifications still contended between scientists. Originally, three forms of colobus monkeys, which include black and white, olive, and red, were placed in the genus *Colobus* (Groves, 2007). However, after 1980 scientists placed olive and red colobus into their own shared genus, *Procolobus* (Groves, 1989). And today red colobus are classified in their own genus,

Piliocolobus. While the number of *Piliocolobus* species has fluctuated between 16 and 18 distinct taxa, today it is generally accepted that there are 17 distinct species of red colobus under *Piliocolobus*, with one species (*Piliocolobus badius*) divided into two subspecies, resulting in 18 distinct forms of red colobus.

The geographic range of red colobus monkeys occurs from Senegal in West Africa to the Zanzibar archipelago in East Africa (Struhsaker, 2010) (Figure 1.2). Red colobus can be found in habitats ranging from primary and secondary closed-canopy rain forests to savanna woodland dry forests (Struhsaker, 2010). Red colobus group size can range from 3 to greater than 100 individuals with significant group size differences within and between a single population. Smaller red colobus group sizes are often found in regions with higher habitat fragmentation, degradation, and human hunting activities (Struhsaker, 2010).

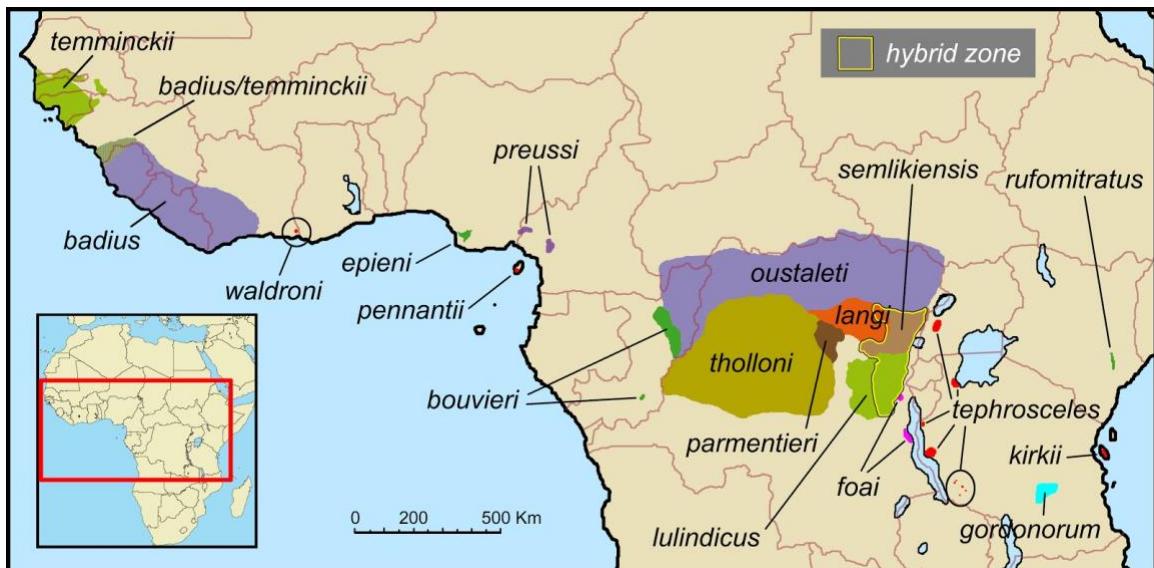


Figure 1.2. Geographic range of all 18 forms of red colobus monkeys (Linder, Cronin, Ting et al. 2020).

1.4.2 Threats to red colobus monkeys and their conservation status

Under the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species, all 18 forms of red colobus are facing threats of extinction with 5 species currently listed as Critically Endangered, 8 as Endangered, and 4 as Vulnerable (Table 1.1)

(IUCN, 2020). The greatest threats to all forms of red colobus are hunting and habitat loss, fragmentation, and degradation from selective logging and land clearing for agriculture (IUCN, 2020).

Red colobus are particularly vulnerable to habitat loss and degradation from logging and agricultural expansion due to their ecological selectivity (Usongo, 2001; Struhsaker, 2010). Compared with other primate species that can even thrive in lightly to moderately logged forests (Remis & Jost Robinson, 2012; Chapman et al. 2018), red colobus have specific habitat requirements in terms of forest structure and tree species needed for survival. Red colobus require mature, primary intact high canopy forests and as a result they are often good indicators of overall forest health with their disappearance from forests indicating signs of habitat degradation (Struhsaker, 2010; Ruiz-Lopez et al. 2016).

In addition to habitat loss and degradation, hunting also has proportionally greater effects on red colobus than other primate species (Struhsaker, 2005, 2010). Compared with other diurnal primate species with which they cohabit, red colobus are less visually alert and tend to have large, noisy groups that are more easily located by hunters. Red colobus monkeys also tend to have a slow flee response to the presence of hunters, providing an easy target (Struhsaker, 2010; Linder & Oates, 2011). Ultimately, red colobus respond poorly to both habitat loss and hunting, putting this group of African monkeys in an especially precarious situation leading to all 18 forms being threatened with extinction.

A collaborative group of international researchers and NGO's launched the forthcoming Red Colobus Conservation Action Plan at the 27th International Primatological Society's Congress in order to galvanize a range-wide conservation effort to conserve and recover all red colobus forms (<https://www.globalwildlife.org>). The plan seeks to raise awareness of red colobus species in their endemic regions and beyond, build conservation and research capacity through training and mentoring, and develop Africa-wide conservation initiatives. The action plan identifies Critically Endangered red colobus species as a top priority for conservation intervention including

the Critically Endangered Preuss's red colobus (*Piliocolobus preussi*), which also recently appeared on the list of the IUCN Primate Specialist Group's 25 Most Endangered Primates (Schwitzer et al. 2015).

Table 1.1 The IUCN red list conservation status for all 18 forms of red colobus (*Piliocolobus* spp.) (IUCN, 2020)

| Scientific Name | Common Name | IUCN Red List Conservation Status |
|------------------------|----------------------------|--|
| <i>P. preussi</i> | Preuss's red colobus | Critically Endangered |
| <i>P. pennantii</i> | Pennant's red colobus | Critically Endangered |
| <i>P. waldroni</i> | Miss Waldron's red colobus | Critically Endangered |
| <i>P. epieni</i> | Niger Delta red colobus | Critically Endangered |
| <i>P. rufomitratus</i> | Tana river red colobus | Critically Endangered |
| <i>P. temminckii</i> | Temminck's red colobus | Endangered |
| <i>P. parmentieri</i> | Lomami red colobus | Endangered |
| <i>P. bouvieri</i> | Bouvier's red colobus | Endangered |
| <i>P. lulindicus</i> | Ulindi river red colobus | Endangered |
| <i>P. tephrosceles</i> | Ashy red colobus | Endangered |
| <i>P. badius</i> | Western red colobus | Endangered |
| <i>P. foai</i> | Foa's red colobus | Endangered |
| <i>P. kirkii</i> | Zanzibar red colobus | Endangered |
| <i>P. langi</i> | Lang's red colobus | Endangered |
| <i>P. gordoni</i> | Udzungwa red colobus | Vulnerable |
| <i>P. oustaleti</i> | Oustalet's red colobus | Vulnerable |
| <i>P. semlikiensis</i> | Semliki red colobus | Vulnerable |
| <i>P. tholloni</i> | Tshuapa red colobus | Vulnerable |

1.5 Preuss's Red Colobus

1.5.1 Taxonomy

Piliocolobus preussi (Figure 1.3; Butynski & Kingdon, 2013) is a monotypic species of red colobus. Some molecular data indicates a possible divergence 0.3 million years ago between *P. preussi* and its closest red colobus population, *Piliocolobus pennantii*, found on Bioko Island (Ting, 2008). Coincidentally, Grub *et al.* (2003) discerned *P. preussi* as a sub-species of *P. pennantii*. However, it's more widely accepted that *P. preussi* is a separate species (Groves, 2005, 2007; Butynski & Kingdon, 2013a). In addition, researchers once thought *P. preussi* to be a sub-species of *Piliocolobus badius* based on morphological and phenotypic characteristics (Napier, 1985; Grub, 1990). But there are important differences between *P. preussi* and *P. badius* including pale inner limbs and ventrum of Preuss's red colobus. In addition, the nearest population of *P. badius* is more than 1,000 km from *P. preussi* with important geographic barriers such as major rivers (Butynski & Kingdon, 2013a). Apart from geographic and morphological distinctions from other red colobus, the vocal repertoire of *P. preussi* also distinguishes it as a separate species (Groves, 2005, 2007; Struhsaker, 2010; Oates, 2011; Butynski & Kingdon, 2013a).

1.5.2 Ecology

P. preussi are highly folivorous and depend on emergent trees for the consumption of young leaves. While this is the most common part of the plant eaten by Preuss's red colobus, they have also been observed consuming fruits, flowers, and buds (Usongo and Amubode 2001; Linder & Oates, 2011). Within KNP, the plant families Sapotaceae and Annonaceae accounted for nearly 50% of all of the food items eaten by *P. preussi* (Butynski & Kingdon, 2013a).

Preuss's red colobus are commonly found foraging in polyspecific associations with groups of at least one other species of monkey (Butynski & Kingdon, 2013a). Edwards (1992) found that in KNP, 92% of *P. preussi* encountered were in these mixed-species groups. These

associations are thought to provide foraging advantages and improve predator detection and avoidance (Gartlan & Struhsaker, 1972).



Figure 1.3. Adult female Preuss's red colobus (*Piliocolobus preussi*) (Butynski & Kingdon, 2013).

1.5.3 Geographic range

Preuss's red colobus is endemic to the lowland, mid-altitude, and submontane moist forests in southeastern Nigeria and western Cameroon in Africa's Gulf of Guinea region. Once more widespread in the forests between Nigeria's Cross River and Cameroon's Sanaga River, Preuss's red colobus' current geographic range is now fragmented into two isolated clusters: one comprising a population in Korup National Park (KNP), Cameroon and across the border in the eastern portion of the Oban Division of Cross River National Park (CRNP), Nigeria, and the other cluster approximately 180 km southeast in Cameroon's Ebo-Makombe-Ndokbou forest block (Figure 1.4).

Most of the current population data available for Preuss's red colobus is derived from the Cameroonian population found in Korup National Park. The first reports of Preuss's red colobus being found in Korup National Park occurred in 1970 (Struhsaker, 1975). Since then, information on the extent, abundance, and conservation status of Preuss's red colobus has been provided through systematic ecological and anthropological research in KNP (Waltert et al. 2002; Linder, 2008; Fonkwo et al. 2015; Hofner et al. 2018). Current estimates suggest that there are less than 5000 red colobus monkeys in KNP (J. Linder pers. comm.).

The first confirmed sightings of Preuss's red colobus in Nigeria did not occur until 1988 (White and Reid, 1988; Oates, 1999). Ecological surveys were conducted in 2001/2002 indicating Preuss's red colobus to be restricted to a small area of the eastern "Ikpan" block of the Oban division bordering Cameroon (Eniang, 2002). The most recent patrol surveying in 2018 indicate that Preuss's red colobus continue to be located in the eastern Ikpan block of the Oban Division along the KNP border with an encounter frequency of 0.001 groups/km but with no substantiated population abundance estimates (Abanyam, 2018).

The earliest evidence of Preuss's red colobus however, comes from skins, skulls, and skeletons collected between 1938 and 1939 in the Ebo-Makombe-Ndokbou forests (Coyler, 1940; Merfield 1957; Napier, 1985). A total of 80 specimens were once collected from these forests,

suggesting that Preuss's red colobus was once relatively abundant and widespread in the Ebo-Makombe-Ndokbou forests (Napier, 1985; Dowsett-Lemaire & Dowsett, 2001). Preuss's red colobus were last sighted in the Makombe and Ndokbou forests in 2001 and 2002 (Dowsett-Lemaire & Dowsett, 2001; B. Morgan pers. obs.) and in the Ebo forest in 2012 (E. Abwe pers. comm.). Surveys in the Makombe and Ndokbou forests in 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) failed to encounter Preuss's red colobus monkeys.

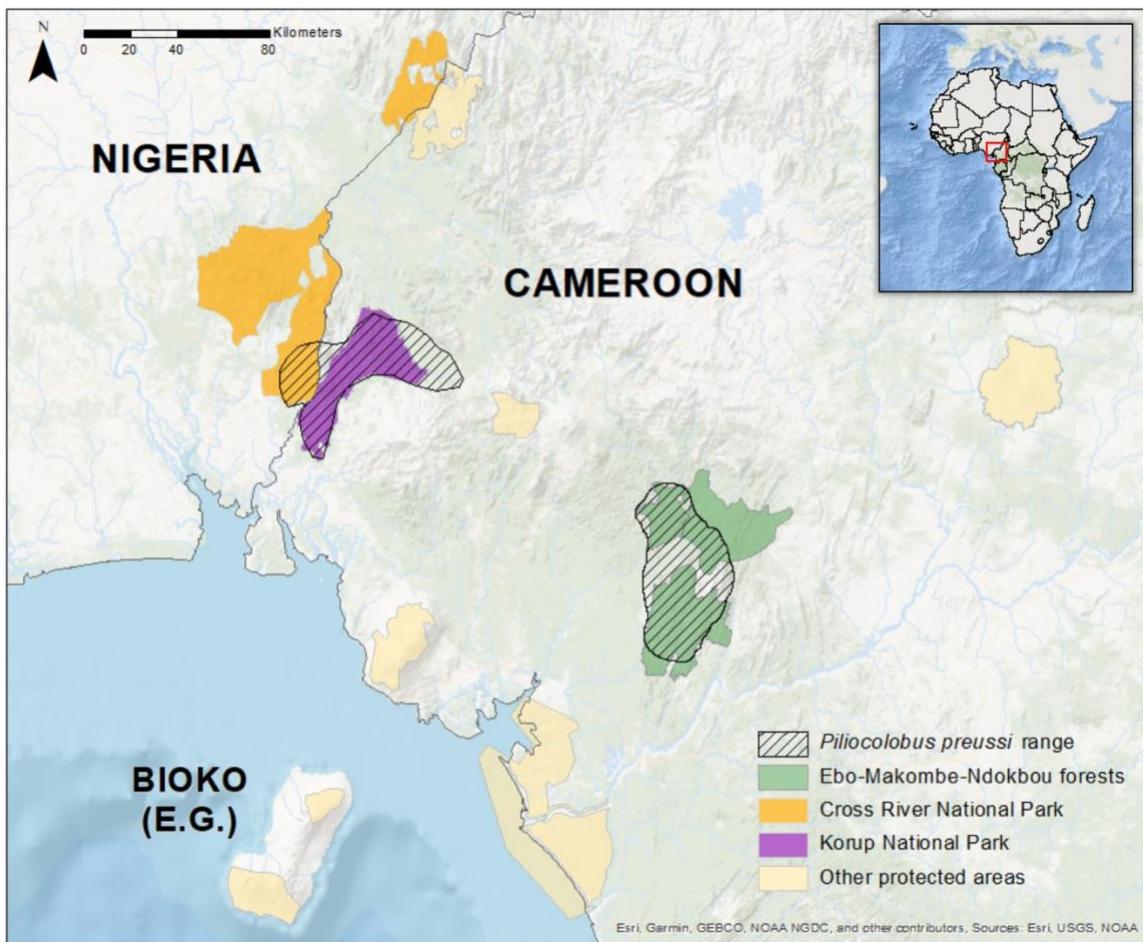


Figure 1.4. Geographic range of Preuss's red colobus (*Piliocolobus preussi*) (adapted from Linder et al. 2019; Linder, Cronin, Ting et al. 2020).

1.5.4 Preuss's red colobus in the Ebo-Makombe-Ndokbou forest

The Ebo (1,400 km²), Makombe (600 km²), and Ndokbou (~ 1,000 km²) forests encompass one of the largest remaining continuous forest blocks of southwestern Cameroon stretching from the Nkam River southward to the Ebo River and northeastward approximately 30 km beyond Mt. Sinai in the Littoral Region of Cameroon (Morgan et al. 2003). The Ebo-Makombe-Ndokbou forests have no legal protection status, despite efforts to gazette the Ebo forest as a national park (Morgan et al. 2011). The Ndokbou forest and regions of the Makombe forest were converted into a logging concession beginning in 2005 with active logging occurring up until 2017/2018. In addition, the Cameroonian government signed a proposal in February 2020 to convert the entire Ebo forest into a logging concession. Ultimately, with no official protection status, the presence of logging operations and subsequent widespread hunting activities continue to threaten primate species in these forests including and especially, Preuss's red colobus. Once more abundant and widespread, with decades of active logging and hunting, the population status of Preuss's red colobus in this region is now relatively unknown.

1.5.5 Protection status

Cameroon is a member of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Preuss's red colobus has some protection based on CITES classifications. In general, Cameroon has one specific law that forbids the hunting and capture of protected wildlife species as per article 78(2) under Law No. 94/01 of January 20, 1994. Section 101 of the law states that it is illegal to possess parts or the whole body of a protected animal with Section 158 specifying a fine of 3,000,000 – 10,00,000 FCFA (~\$5,000 – \$17,000) and 1-3 years of imprisonment for the killing or capture of protected animals either outside the hunting season or within protected areas where hunting is prohibited.

Cameroon Order No. 0648/MINFOF of December 18, 2006 defines animal protection status by classes A, B, and C according to their degree of protection. Species in Class A are

completely protected and are forbidden to be killed except in cases where animals constitute danger to persons, property, or as a response for the protection of livestock or crops. Class B species are protected but may be hunted, captured or killed with a specific hunting permit. Class C species are partially protected and their capture or killing are regulated by the minister in charge of wildlife. Section 6 states that the protection classification of any species not specifically listed in the Order follows CITES Appendix I, II, and III classification scheme and/or the IUCN Red List Threatened species categories (Vulnerable, Endangered, Critically Endangered, Extinct in the wild or Extinct). *P. preussi* is not listed in the original Cameroon Order No. 0648/MINFOF and therefore, based on its official status as Critically Endangered by the IUCN Red List, *P. preussi* falls under the Cameroon Class A threat category. This indicates that within the country of Cameroon, *P. preussi* is supposed to hold complete protection status and cannot be hunted unless under specific scenarios described above.

Other protections include the EU Wildlife Trade Regulations listing *P. preussi* under Annex A in 1996 (Council Reg. (EC) No. 338/97 of December 9, 1996) which states that the species cannot be traded or used for commercial purposes. In addition to listing *P. preussi* under the Appendix II by CITES in 1977, in 2015 CITES also submitted a recommendation to Nigeria to suspend trade in *P. preussi* (CITES Notif. No. 2015/014).

In regard to general hunting regulations in Cameroon under Law No. 94/0, all persons are required to obtain hunting permits and licenses. In addition, the law declares that unless specially authorized, hunting at night especially with head lamps or any lighting equipment is forbidden along with certain types of guns including those used by the military, firearms capable of firing more than one cartridge with one press on the trigger, trenches and dane guns. The law also states the administration in charge of wildlife may regulate the caliber or type of arms for hunting certain animals and prohibit the use of certain types of arms or ammunition.

Similarly, Nigeria enacted the Endangered Species (Control of International Trade and Traffic) Act in 1985 prohibiting the hunting or trading of animal species designated by the “First

“Schedule” as threatened with extinction. “Second Schedule” species are animals that may become threatened but are not necessarily threatened with extinction and may be hunted or traded with the possession of a proper license. Technically the law lists all colobus monkeys including *Colobus* spp. and *Procolobus* spp. (the former genus of red colobus monkeys) as First Schedule species indicating hunting and international trade absolutely prohibited. “All monkeys (except those specified in First Schedule)” are designated under the Second Schedule classification. Ultimately, the only regions where it is strictly illegal to hunt Preuss’s red colobus are within the protected national parks of Cross River National Park, Nigeria and Korup National Park, Cameroon.

1.6 Research Questions and Objectives

The goals of this study are to assess the population status of and threats to Preuss’s red colobus and other primates in the Ebo-Makombe-Ndokbou forests through ecological research and to inform conservation efforts to improve the protection the region’s most Threatened primate species including and especially, Preuss’s red colobus. To accomplish these goals I first addressed the following research questions concerning primate species richness and abundance in the Ndokbou forest.

1. How do species richness and the relative abundance of diurnal primate species vary among different areas of the Ndokbou forest?

Predictions:

- a. Based on reports from 2018 primate surveys, Preuss’s red colobus will exhibit the lowest primate encounter frequency in the Ndokbou forest
- b. Primate encounter frequencies will increase as distances from roads and villages increases
- c. Primate encounter frequencies will increase as terrain ruggedness increases
- d. Primate encounter frequencies will increase as slope increases

2. How does the relative abundance of primate species in the Ndokbou forest compare to that of the Makombe forest and Korup National Park?

Predictions:

- a. Primate encounter frequencies will be similar to those of the nearby unprotected Makombe forest
- b. Primate encounter frequencies will be lower than those of the protected Korup National Park

Sightings of Preuss's red colobus are confirmed within the Ebo and Makombe forests from surveys conducted from 2000 and 2001 (Dowsett-Lemaire & Dowsett). Additional confirmed sightings occurred in the Ebo forest from 2009 to 2011 (Morgan, 2011) and 2012 (E. Abwe pers. comm.). Less is known about the current extent of Preuss's red colobus in the Ndokbou forest. Reports from hunters indicated the possible presence of Preuss's red colobus in the Ndokbou forest near Mt. Sinai and the Grand Nouya River (Dowsett-Lemaire & Dowsett, 2001). Building on previous surveys conducted in 2018 in the Ndokbou forest (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan), my objectives were a) to quantify the presence/absence and relative abundance of Preuss's red colobus and other primates in the Ndokbou forest with special attention to the areas around Mt. Sinai, and b) to compare these estimates with those of the most current and extensive abundance estimates of primates in Korup National Park. Given that the Ndokbou forest has never had formal protection, has a history of being selectively logged, and hunting for bushmeat is widespread, I predicted that Preuss's red colobus and other relatively large-bodied primates would be less abundant than smaller-bodied *Cercopithecus* primate species. I also predicted that primate abundance would increase with geographic variables associated with more rugged characteristics of the forest including increased distances from roads and villages, increased slope, and increased terrain ruggedness, especially around Mt. Sinai, because these environmental features can provide refuge for hunted primates or

primates in logged forests (Butynski & Koster, 1994; Astaras, 2009). Finally, I predicted that overall abundance estimates of Preuss's red colobus and other diurnal primates found in the Ndokbou and Makombe forests would be less than those found in Korup National Park, which has never been logged and which has been associated with a number of conservation interventions (e.g., anti-poaching patrols, development schemes, ecological monitoring).

I then addressed the following research questions related to human activities threatening primate species richness and abundance.

1. How does hunting activity vary among different areas of the Ndokbou forest?

Predictions:

- a. Hunting sign encounter rates will increase as distances from roads and villages decrease
- b. Hunting sign encounter rates will increase as terrain ruggedness decreases
- c. Hunting sign encounter rates will increase as elevation decreases
- d. Hunting sign encounter rates will increase as slope decreases

2. How do estimates of hunting pressure vary between hunting sign encounter rates calculated from traditional forest surveys and gunshot frequency calculated from passive acoustic monitoring?

Prediction:

Acoustic sensors will estimate greater gun hunting pressures than forest survey gun hunting estimates

3. How does gun hunting activity vary temporally?

Predictions:

- a. Greater levels of gun hunting will occur during night hours than day hours
- b. Greater levels of gun hunting will occur during the weekdays than on the weekends
- c. Greater levels of gun hunting will occur during months of the dry season (November - December) than months of the wet season (September - November)

4. How do estimates of gun hunting activity in the Ndokbou forest compare to those of the Makombe forest and Korup National Park?

Prediction:

The Ndokbou and Makombe forests will exhibit greater levels of gun hunting than the protect Korup National Park

5. How does logging activity and intensity vary across the Ndokbou forest?

Prediction:

Logging sign encounter rates will be greatest in regions closest to villages and roads

My objectives were to a) assess the encounter frequency and geographic distribution of hunting signs in the Ndokbou forest, b) assess the spatial and temporal distributions of gun hunting activities in the Ndokbou forest using passive acoustic monitoring methods, c) compare the geographic distribution of gun hunting identified by traditional forest survey methods to that of passive acoustic monitoring data, d) compare spatial and temporal patterns of gun hunting in the Ndokbou forest to those in Korup National Park where gun hunting has previously been monitored using passive acoustic monitoring, and e) assess the encounter frequency and geographic distribution of logging signs in the Ndokbou forest. I predicted that hunting intensity would be greatest nearest to villages and major roads where forest access is easiest and lowest in more rugged, hard to access areas. Based on gun hunting patterns found in Korup National Park using acoustic monitoring methods (Astaras et al. 2017), I predicted that a) gun hunting activity would be greatest during the night hours, b) gun hunting frequency would increase from wet season months (September - November) into dry season months (November - December), c) gun hunting would be greatest during the weekdays leading up to the Saturday and Tuesday market days, d) passive acoustic monitoring data would identify greater levels of gun hunting compared with the geographic distribution of gun hunting identified by forest surveys, and e) the Ndokbou

forest would exhibit a greater frequency of gun hunting than that of Korup National Park where there have been active efforts by ranger patrols to deter hunting activities.

Habitat loss is shown to be one of the greatest threats to the survival of Preuss's red colobus due to their ecological sensitivity and requirements of intact, high canopy forests (Struhsaker, 2010). In addition, there is documentation that other primates including the drill and chimpanzee are threatened by logging concessions within the Ndokbou forest (Dowsett-Lemaire & Dowsett, 2001). Based on ease of access and forest ruggedness, I predicted that logging intensity would be greatest nearest to villages and major roads where forest access would be easiest and less rugged.

With limited previous data available on the distribution and abundance of primate species found in Ebo-Makombe-Ndokbou forests, the results from this study can be used as a baseline for future monitoring and evaluations of primate populations. This in turn can contribute to overall conservation efforts in the Ebo-Makombe-Ndokbou forests by identifying regions of the forest that contain important primate species populations with current abundance estimates.

1.7 Description of Study Region

1.7.1 Location and topography

This study was conducted in the ~1,000 km² Ndokbou forest of the continuous Ebo-Makombe-Ndokbou forest block. The Ebo (1,400 km²), Makombe (600 km²), and Ndokbou (~1,000 km²) forests encompass one of the largest remaining continuous forest blocks of southwestern Cameroon stretching from the Nkam River southward to the Ebo River and northeastward approximately 30 km beyond Mt. Sinai in the Littoral Region of West Cameroon (Morgan et al. 2003). The forest block lies approximately 180 km southeast of Korup National Park and the Cameroon/Nigeria border (Figure 1.5). The Ndokbou forest stretches southeast of the Makombe forest (600 km²) from the middle Makombe river to the village of Ndikiniméki and north to the village of Tongo. The Ndokbou forest stretches to the south where it becomes the

Ebo forest (1,400 km²). Together this forest block comprises approximately 3,000 km² of open and closed-canopy semi-deciduous and evergreen lowland and submontane rainforest of the Atlantic forest (Letouzey, 1968).

Elevation of the Ebo-Makombe-Ndokbou forests range from 100 m to approximately 1,200 m above sea level. However, the terrain of Ndokbou and Ebo forests in particular, are characterized by steep topography with many points of elevation reaching above 1,000 m. The region containing Mt. Sinai (4°34'N, 10°30' E) within the central portion of the Ndokbou forest, contains ridgelines reaching 1,300 m. Major rivers of the region include the Ebo River (which extends north to south within the Ebo forest), the Makombe river (which forms the southern boundary of the Makombe forest and the southwest region of the Ndokbou forest and ultimately joins with the Nkam river to form the Wouri river), and the Grand Nouya River (a tributary of the Makombe River running north and south through the center of the Nbokbou forest) (Figure 1.6).

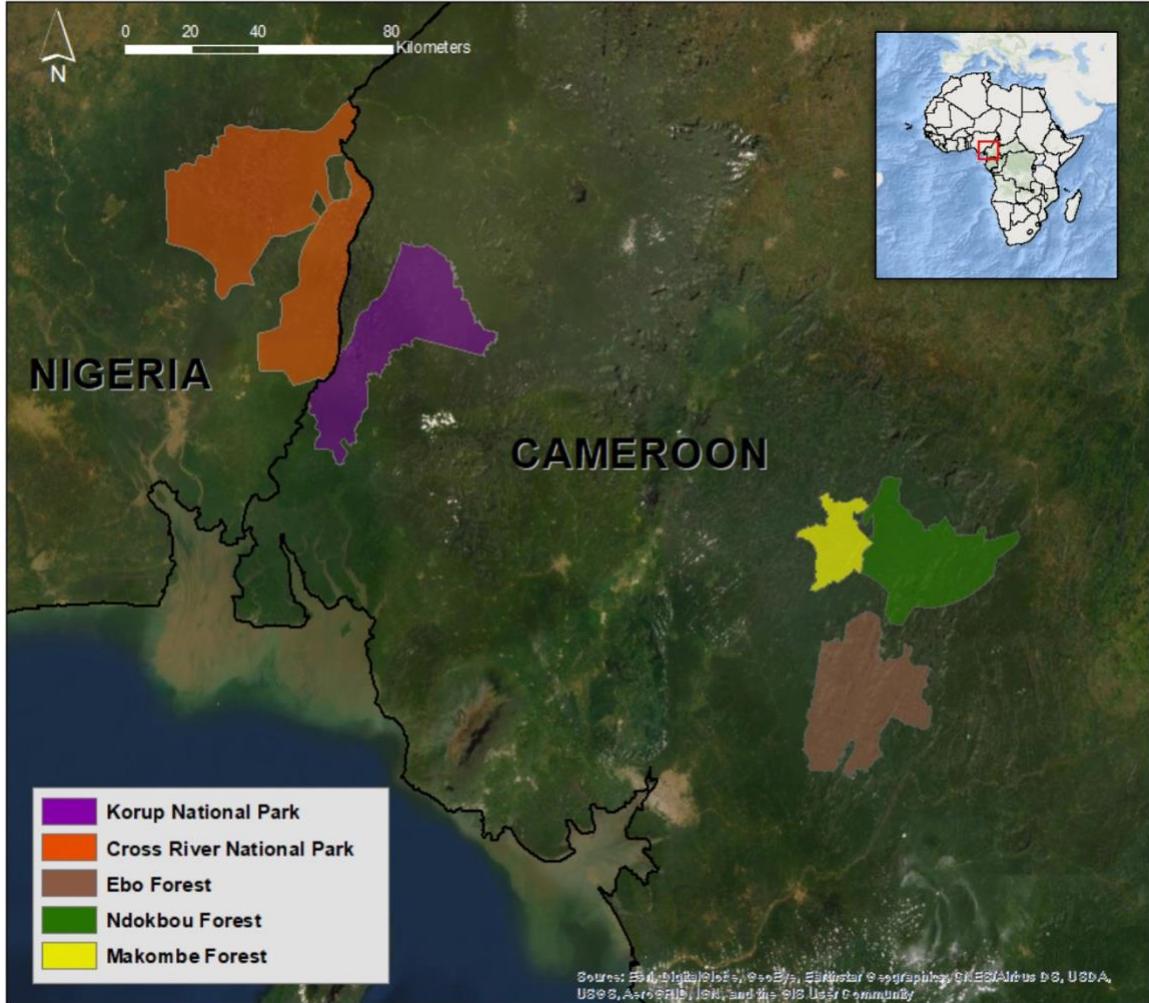


Figure 1.5. The location of the Ebo-Makombe-Ndokbou forest block in relation to Korup National Park and Cross River National Park, Nigeria.

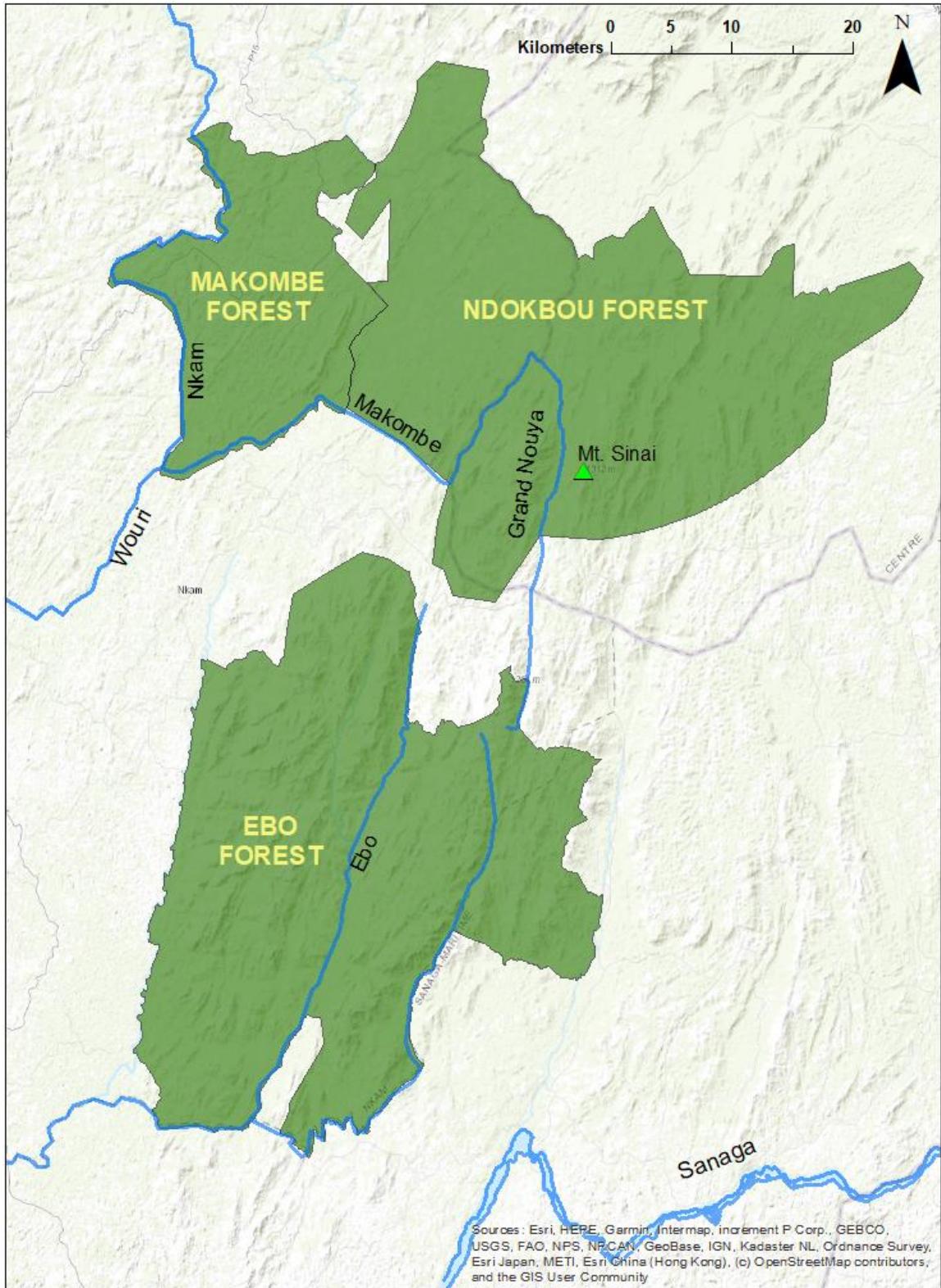


Figure 1.6. The location of Mt. Sinai and major rivers within the Ebo-Makombe-Ndokbou forest region.

1.7.2 Climate

The Ebo-Makombe-Ndokbou region is characterized by a wet season occurring from March to November and a dry season between the months of December to February (Abwe, 2018). While there's no rainfall and climate data specific to the Makombe and Ndokbou forests, climate and rainfall patterns are available from data collected at two research stations in the central region of the Ebo forest (Abwe, 2018). Overall mean annual precipitation between 2013 and 2015 was approximately 3,700 mm (Ley et al. 2018). The driest months of the year are December and January with an average monthly rainfall of less than 50 mm/month. Rainfall peaks during the wet season between the months of July and October with an average monthly rainfall between 400 mm and 550 mm (Figure 1.7).

Between 2013 and 2015, the average minimum temperature in the Ebo forest was 22°C with a maximum average temperature of 26°C. Monthly temperature fluctuation was 4°C with the highest average temperature occurring in February during the dry season and the lowest average temperature occurring in September during the wet season (Abwe, 2018; Ley et al. 2018). Higher mean temperatures are observed at lower elevations in comparison to higher elevations (Ley et al. 2018).

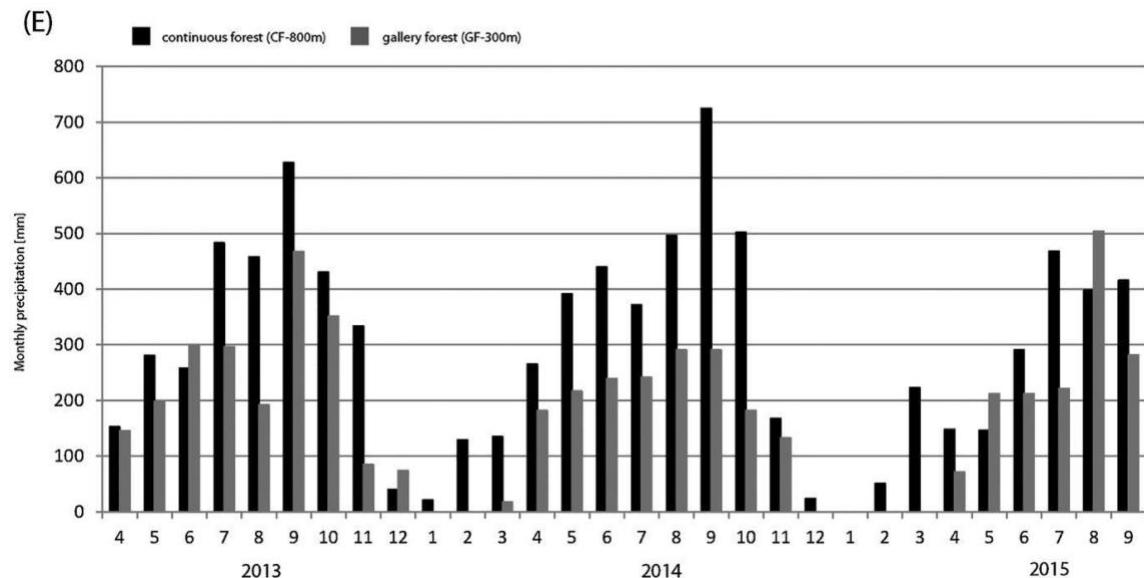


Figure 1.7. Monthly precipitation (mm) amounts between 2013 and 2015 for a single site located in the Ebo forest represented by black bars (continuous forest CF-800m) (Ley et al. 2018).

1.7.3 Vegetation

The Ebo-Makombe-Ndokbou forest is characterized by open and closed canopy semi-deciduous and evergreen lowland and submontane rainforest of the Atlantic forest (Letouzey, 1968; Abwe, 2018). Lower elevations are characterized by open and closed-canopy evergreen and semi-deciduous forests with higher altitudes containing evergreen closed-canopy submontane vegetation (Abwe, 2018; Dowsett-Lemaire & Dowsett, 2001). Habitat degradation from human activity have altered plant community structure at lower and upper elevations. In more human-modified landscapes of the forest, closed-canopy mature submontane species of *Garcinia* dominate the rainforest with more open-canopy secondary forests occurring at lower elevations due to old, abandoned plantations (Abwe, 2018). Upper-canopy species that are commonly found include, *P. angolensis* and *Santiria trimera*. Middle and lower canopies are mainly dominated by *Uapaca guineensis*, *Tabernaemontana crassa*, *Oncoba welwitschii*, and *Drypetes* species (Abwe, 2018).

In more pristine areas of the rainforest, common upper-canopy species include *Scyphocephalium mannii*, *Desbordesia glaucescens*, and *Pycnanthus angolensis*. Middle and lower canopies contain mainly *Coula edulis* and different species of *Diospyros* and *Drypetes* (Abwe, 2018). Specifically within the Ndokbou forest, logging activity (described below) has altered habitats of the northern region of this forest. Common species found within abandoned logging remnants and in particular abandoned logging roads, include *Aframomum angustifolium* and *Musanga cecropioides* (pers. obs.). Common tree species found in the Ndokbou forest that are also heavily sought after by logging companies include *Lophostoma alata* and *Erythrophleum ivorense*.

1.7.4 Human populations and activities

The human population of Cameroon is currently estimated at approximately 25,876,000 individuals with populations concentrated in the west and northern regions of the country (UN, 2019b). While maintaining the fourth highest population of all Central and West African countries, Cameroon contains the second highest human population density of mainland Central and West African countries at 54.7 people per square kilometer (Table 1.2). Located less than 150 km from the Ebo-Makombe-Ndokbou forest block is the largest city in Cameroon and country capital of Yaoundé (pop. 3.922 million). Less than 50 km from the Ebo forest is Douala, Cameroon's industrial capital and second largest city after Yaoundé. Being situated near such large centers of human populations, the Ebo forest in particular has a long history of village settlements. There were several villages located inside the Ebo forest, however almost all were abandoned following the civil strife of the Bamiléké War between 1959 and 1960 (Dowsett-Lemaire & Dowsett, 2001; Morgan et al. 2003). Today there are a number of villages that closely border the Ebo-Makombe-Ndokbou forest block with mainly semi-permanent hunting camps located inside the forests (Whytock et al. 2014).

The people inhabiting this region are mainly from the Bassa and Banen ethnic groups (Fuashi et al. 2019). However, due to current civil strife and violence occurring in the North-West and South-West regions, many people from those regions have been forced to flee their villages and relocate to other regions of Cameroon including the Littoral region (Okereke, 2018). Therefore, the region has become a mix of socio-cultural, linguistic, economic and political backgrounds (Fuashi et al. 2019).

Key villages closely bordering both the Ndokbou and Ebo forests include Yingui, Ndokmen Nord, Logndeng, and Iboti (Figure 1.8). Of these villages, Yingui is the largest with a population of approximately 2,304 (BUCREP, 2005). It is also most prominent as it is centrally located to all three forests and is one of the only villages in the area with electricity. Yingui is also an important location of key resources for these remote forest communities; it is the location

of one of the only hospitals in the region, it holds a Ministry of Forests and Wildlife (MINFOF) office, and there are public market days held every Saturday and Tuesday. Many surrounding villages also use Yingui as a transportation hub for hired car travel to-and-from Douala.

Most people in the region currently practice small-scale cocoa and other small-scale plantation agriculture, fishing, and Non-Timber Forest Product (NTFP) extraction. Hunting for bushmeat is also a key human activity in the region, constituting a key source of income and animal protein for local villages (Fuashi et al. 2019). The close proximity of these forests to the city of Douala supports key markets for forest products and wildlife, supplying the bushmeat trade (Morgan et al. 2011, Whytock & Morgan, 2010; Morgan et al. 2011; Abwe, 2018). People from the Ebo-Makombe-Ndokbou area can often earn higher prices for bushmeat and NTFPs in the Douala markets rather than selling their products at the local Yingui market. Car hires for personal transport from Yingui to Douala were commonly observed transporting people with bushmeat (pers. obs.).

Table 1.2. Total human population estimates (total # of individuals) and population densities (persons/km²) for countries located in Sub-Saharan Central and West Africa as of July 1, 2019 (UN, 2019b).

| Country | Human Population (total # of individuals) | Population Density (persons/km²) |
|----------------------------------|--|--|
| Angola | 31,825,000 | 25.5 |
| Cameroon | 25,876,000 | 54.7 |
| Central African Republic | 4,745,000 | 7.6 |
| Congo | 5,381,000 | 15.8 |
| Democratic Republic of the Congo | 86,791,000 | 38.3 |
| Equatorial Guinea | 1,356,000 | 48.3 |
| Gabon | 2,173,000 | 8.4 |
| Nigeria | 200,964,000 | 220.7 |

Sao Tome and Principe

215,000

224.0

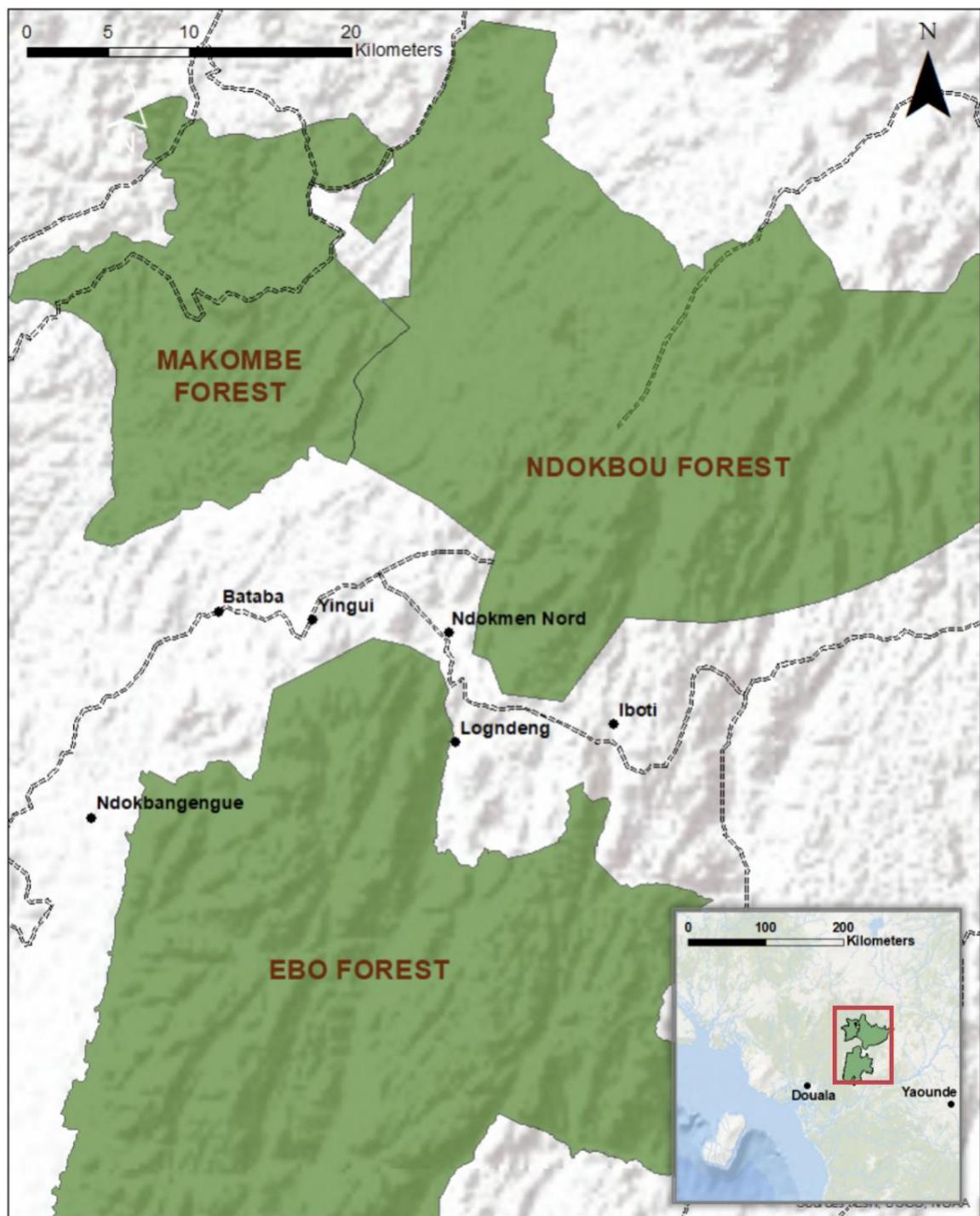


Figure 1.8. Locations of villages along the only motorable road bordering the Ebo and Ndokbou forests.

1.8 Primates of the Region

1.8.1 Taxonomy and conservation status

The Ebo-Makombe-Ndokbou forest block contains ten species of diurnal primates (Table 1.3) and seven species of nocturnal primates. *Piliocolobus preussi* along with *Pan troglodytes ellioti*, *Mandrillus leucophaeus leucophaeus*, and *Cercopithecus erythrotis camerunensis* are all subspecies endemic to the Nigeria-Cameroon Cross River region in the north and the Sanaga River in the south (Grubb et al. 2000). *Cercocebus torquatus* and *Allochrocebus preussi* are both endemic to the Gulf of Guinea rainforest region with *A. preussi* found on both the mainland and Bioko Island (Maisels et al. 2019; Cronin et al. 2019a). I follow the nomenclature for *Cercopithecus nictitans* established by Grubb et al. (2000; 2003) which distinguishes a Bioko Island form of putty-nosed as *C. nictitans martini*, and two mainland subspecies: *C. nictitans ludio* and *C. nictitans nictitans*. For this study, I use the *C. nictitans* nomenclature for the *C. nictitans ludio* subspecies found in southeast Nigeria and southwest Cameroon between the Cross and Sanaga rivers (Cronin et al. 2019b).

Similarly, there is some debate regarding subspecies classifications of *Cercopithecus pogonias*. Gautier-Hion (2013a) and Mittermeier et al. (2013) include the subspecies, *C. pogonias pogonias*, belonging to both Bioko and Nigeria-Cameroon forms of *C. pogonias*. However, Gautier-Hion et al. (1999) recognizes the mainland form as a distinct subspecies from the Bioko subspecies. For the purpose of this study I refer to the Ebo-Makombe-Ndokbou form of *C. pogonias* as the *C. pogonias pogonias* subspecies.

Table 1.3. Diurnal primate species found in the Ebo-Makombe-Ndokbou forest with average male + female body weight (kg) (Linder, 2008; Kingdon, 2015) and each species' IUCN conservation status (IUCN, 2020)

| Common Name | Scientific Name | Body Weight (kg) | IUCN Red List Status |
|-------------------------------|--|-------------------------|-----------------------------|
| Nigeria-Cameroon chimpanzee | <i>Pan troglodytes ellioti</i> | 35 | Endangered |
| Mainland Drill | <i>Mandrillus leucophaeus leucophaeus</i> | 11.14 | Endangered |
| Preuss's guenon | <i>Allochrocebus preussi</i> | 3.5 - 7.0 | Endangered |
| Red-capped mangabey | <i>Cercocebus torquatus</i> | 8.70 | Endangered |
| Preuss's red colobus | <i>Piliocolobus preussi</i> | 7.70 | Critically Endangered |
| Gorilla | <i>Gorilla gorilla</i> ssp. | 58 - 191 | Critically Endangered |
| Putty-nosed guenon | <i>Cercopithecus nictitans</i> | 5.37 | Near Threatened |
| Mona guenon | <i>Cercopithecus mona</i> | 4.09 | Least Concern |
| Cameroon red-eared guenon | <i>Cercopithecus erythrotis camerunensis</i> | 3.50 | Vulnerable |
| Golden-bellied Crowned monkey | <i>Cercopithecus pogonias pogonias</i> | 3.43 | Vulnerable |

Of the ten diurnal primate species found in the Ebo-Makombe-Ndokbou forest, the World Conservation Union (IUCN) Red List of Threatened Species lists two of the species as Critically Endangered, four species as Endangered, and two as vulnerable (IUCN 2020) (Table 1.3). The subspecies of putty-nosed monkey in the Ebo-Makombe-Ndokbou forest (*C. nictitans ludio*) is not used on the IUCN Red List and consequently there is no listing. Therefore I use the conservation status listed for the species *C. nictitans*, which was recently elevated from Least

Concern status to Near Threatened status in 2019 due to increasing human population densities, hunting intensity, and deforestation (IUCN, 2020).

1.8.2 Habitat of primate species

Cercopithecus primate species can be found in a variety of forest types. *C. erythrotis*, *C. nictitans*, and *C. mona* can be found in both primary and secondary forests, but *C. mona* is most abundant in mangrove swamp areas and less successful in secondary forests. It is least abundant in mature primary forests and successfully inhabits forest edges, cultivated areas, and degraded habitat (Gartlan & Struhsaker, 1972; Oates, 2008). *C. erythrotis* and *C. nictitans* can be abundant in mature and older secondary forests, but seem to prefer younger lowland secondary forests (Gartlan & Struhsaker, 1972; Oates et al. 2008). *C. pogonias* on the other hand, is most successful in mature forests rather than secondary forests with younger vegetation (Gartlan & Struhsaker, 1972; Wolfheim 1983). This species also appears to avoid areas close to human habitation. It has also been noted that compared with *C. nictitans* and *C. erythrotis*, *C. pogonias* has a greater overall range with seasonal movement to high food concentrations (Wolfheim, 1983; Gautier-Hion, 2013a).

The vertical distribution of *C. nictitans* and *C. pogonias* is primarily in the middle to upper strata of the forest canopy (Gartlan & Struhsaker, 1972). *C. nictitans* are rarely found on the forest floor. In comparison, *C. erythrotis* and *C. mona* occupy more of the lower forest strata (Linder, 2008).

P. preussi depend on intact, mature, high canopy mid-altitude and sub-montane moist forest up to 1,000 m (Butynski & Kingdon, 2013a). They are very sensitive to forest disturbance and habitat degradation from human activities (e.g. logging operations) and spend most of their time in the upper canopy of the forest (Linder et al. 2019).

C. torquatus has been observed in a wide array of habitats, although consistently no more than 250-350 km from coastal regions (Ehardt, 2013; Maisels et al. 2019). While it is observed in

intact lowland rain forests and mangrove swamps (Gartlan & Struhsaker, 1972), it's most common in high canopy forests. But this species is also known to inhabit young secondary forests around cultivated areas (Maisels et al. 2019). *C. torquatus* spend considerable time on the ground feeding or when fleeing. But they're vertical distribution is also dependent on activity with feeding occurring from the ground to 40 m high in the canopy (Ehardt, 2013).

A. preussi is found in primary and secondary lowland, submontane and montane forest including forest patches in montane grasslands (Gartlan & Struhsaker, 1972; Butynski, 2013). They can be found at elevations ranging from 100 – 3,000 m. However, this species is most abundant in montane forests above 800 m in elevation. The Bioko form of this species (*A. p. insularis*) is rarely found below 900 m. It's also notable that *A. preussi* is found in some of the wettest areas of Africa; inhabiting regions with annual rainfall amounts between 2,000 and 9,000 mm (Butynski, 2013; Ndeloh, 2019). Semi-terrestrial, *A. preussi* spend much of their time foraging on the ground but are also often seen in trees. Remote areas where there are few interactions with people or hunters, show that *A. preussi* travel and forage primarily above ground (Butynski, 2013).

M. l. leucophaeus is most abundant and primarily found in primary and mature secondary forests (Oates & Butynski, 2008). While it is possible to find them sometimes in young secondary forests, they prefer primary or mature secondary forests. Groups do occur at lower altitude between 0-600m. but they tend to try and avoid human activity including hunters by favoring higher, more difficult terrain. *M. l. leucophaeus* are closed-canopy specialists and rarely traverse marginal habitats (Astaras, 2009). They also avoid cultivated farmland or areas near human habitation (Astaras, 2009; Dietrich Schaaf et al. 2013;).

P. t. ellioti is found in a range of primary and secondary forests including moist lowland, montane and submontane, dry forest, and forest galleries (Sesink Clee et al. 2015; Oates et al. 2016). Gartlan & Struhsaker (1972) observed this species primarily in montane forests above 1,000m with a greatest abundance in mature and older secondary forests. *P. t. ellioti* are found in

both closed and open-canopy habitats of primary and secondary forests. Abwe (2018) noted that there is large variation in habitat preference based on rainfall seasonality, vegetation composition, and fruiting patterns. However, for nesting they prefer closed-canopy forests in primary forest regions (Abwe, 2018).

An unidentified sub-species of *G. gorilla* has only been found in regions of the Ebo forest with no confirmation of its presence in the Makombe or Ndokbou forests. It is yet to be determined if this subspecies is a Cross River Gorilla (*Gorilla gorilla diehli*) or a Western Lowland Gorilla (*Gorilla gorilla gorilla*) (Maisels et al. 2018). For the purpose of this study, I will not be focusing on *G. gorilla* as they are only known to occur in the Ebo forest.

1.8.3 Diets of primate species

Ecological niche separation including differences in body size and physical abilities to eat certain foods most likely separate *M. l. leucophaeus*, *C. torquatus*, and *P. t. elliotti* from the smaller guenon species (*Cercopithecus* spp.) in diet preferences. Among the smaller guenons, *C. pogonias* and *C. erythrotis* are the most frugivorous, however, they have also been observed eating flowers (Gartlan & Struhsaker, 1972; Butynski & Kingdon, 2013b; Gautier-Hion, 2013a). In addition, they both will occasionally eat insects (Butynski & Kingdon, 2013b).

C. nictitans primarily eat fruits and seeds (~ 70% of diet) followed by leaves (Gartlan & Struhsaker, 1972; Gautier-Hion, 2013b). However, there is seasonal variation in their diet with an inverse relationship between the consumption of fruits and leaves. *C. nictitans* will sometimes eat insects including caterpillars and ants (Tutin et al. 1997; Gautier-Hion, 2013b). Of the guenons, they are also the most common found foraging in polyspecific associations with other primate species (Gartlan & Struhsaker, 1972).

Of the guenons, *C. mona* is the least frugivorous but fruits still make up the majority of their diet followed by seeds when ripe fruits are not available (Matsuda, 2007; Olaleru, 2017). In

addition, *C. mona* will also insects, primarily during the rainy season (Matsuda, 2007). The most rarely eaten plant part by *C. mona* are flowers and nectar.

M. l. leucophaeus are omnivorous and forage extensively on the ground (Dietrich Schaaf et al. 2013). The largest portion of their diet (~ 72%) consists of fruits and seeds (Astaras, 2009). However, they also consume a significant amount of insects; primarily ants, termites, and sometimes orthopterans (Oates & Butynski, 2008; Dietrich Schaaf et al. 2013). To a lesser degree, *M. l. leucophaeus* will consume leaves, flowers, bark, fungi, and eggs of birds, reptiles, and snails (Astaras, 2009; Dietrich Schaaf et al. 2013).

While *C. torquatus* sometimes feed on the forest floor, they are primarily found foraging for fruit within the tree canopy (Cooke, 2012; Ehardt, 2013). After fruit, *C. torquatus* primarily eat seeds, followed by young leaves and shrubs (Ehardt, 2013). Although more rare, they have also been observed supplementing fruits and seeds with insects and crabs (Cooke, 2012; Ehardt, 2013).

A. preussi are identified as opportunistically omnivorous. About 50% of their diet consists of fruit and seeds, but they will opportunistically consume invertebrates and small aquatic animals (Beeson et al. 2996; Butynski, 2013; Ndeloh et al. 2019). After fruit, *A. preussi* most frequently consume shoots and leaves (Beeson et al. 1996).

P. t. ellioti are also omnivorous but fruits constitute the majority of their diet (Gartlan & Struhsaker, 1972; Morgan et al. 2012; Dutton & Chapman, 2015; Oates et al. 2016; Abwe, 2018). In fact, figs alone comprise half of their diet (Dutton & Chapman, 2015). However, *P. t. ellioti* also eat leaves, bark, stems, and small mammals (Gartlan & Struhsaker, 1972; Morgan et al. 2012; Oates et al. 2016). *P. t. ellioti* have been observed using a variety of tools to extract food. They make tools from plant parts to extract bees, ants, and termites from insect nests and stone hammers in order to crack nuts (Morgan et al. 2011, 2012; Oates et al. 2016; Abwe, 2018).

1.9 Threats to Preuss's red colobus and other diurnal primates in the Ebo-Makombe-Ndokbou forests

1.9.1 Hunting and its importance

Hunting in the Ebo-Makombe-Ndokbou forests for bushmeat can be an important source of protein and a major form of subsistence for local communities surrounding these forests (Whytock & Morgan, 2010; Whytock et al. 2014; Fuashi et al. 2019). Bushmeat supplies 30-80% of protein consumed by rural, forest-dwelling communities in Cameroon (Lescuyer & Nasi, 2016). LeBreton *et al.* (2006) conducted interviews on hunting and bushmeat consumption exclusively in rural villages of southern Cameroon and found that 98% of respondents reported eating bushmeat and 42% reported hunting bushmeat. Villages located in rainforest regions at higher elevations reported the greatest amount of bushmeat consumption. In addition, 10% of hunters reported hunting bushmeat as a source of income and 17% for home consumption (LeBreton et al. 2006).

While bushmeat can be an important form of subsistence, selling bushmeat also constitutes a primary source of income for these communities (Whytock & Morgan, 2010; Whytock et al. 2014; Fuashi et al. 2019). Many villages participate in small-scale cocoa agriculture for income, however, in the late 1980's there was a drastic fall in world prices of cocoa, causing a major blow to Cameroon's economy which relied heavily on the production of cocoa (Duguma et al. 2001; Ichikawa, 2006). While cocoa prices have gradually increased since this downfall, the initial economic hit during that time produced an increase in bushmeat hunting as an alternative source of income (Ichikawa, 2006; Linder, 2008). When comparing villages along the Ebo and Ndokbou forests, Fuashi *et al.* (2009) found that villages located closest to Douala had the greatest mean bushmeat offtake of 61.06 animals per hunter. It was also noted that upon leaving the forest, hunters would often sell their harvest at the forest entrance or hire porters to transport bushmeat directly to urban bush meat traders from Douala (Fuashi et al. 2019). With

these communities being in such close proximity to Douala, one of Cameroon's largest economic hubs, local villagers can earn substantial income from hunting and selling bushmeat (Fa et al. 2014).

1.9.2 Hunting methods and bushmeat offtake

Current methods used for hunting in the region include guns, wire snare traps, dogs, machetes, nets, and hands (LeBreton et al. 2006; Fuashi et al. 2019). Approximately 55% of bushmeat is killed using guns in this region (Fuashi et al. 2019). The most commonly used gun is a 12-gauge, single barrel shotgun (Linder, 2008). The “shotgun shell” or “cartridge” holds the ammunition of a shotgun and after a shot is fired and the ammunition is used, the empty shotgun shell is deposited on the ground. When hunters neglect to pick up the empty shotgun shell cartridge, this provides evidence of hunting in the forest.

Wire snares are the second most used hunting method with approximately 35% of animals killed using this method. Two types of wire snare traps are used by hunters: free and barrier traps. Free traps use a wire noose connected to a bent-over sapling under tension that is usually placed on a wildlife trail. When an animal puts part of its body in the noose, this moves and trips the sapling causing it to fling backward, tightening the noose around the animal, and lifting it off of the ground. Barrier traps are constructed using palm fronds to form short fences about 70mm tall with varying lengths and the wire noose is then placed at various intervals along the fence. A single poacher was found to average 166 and 1,242 free and barrier traps respectively each year (Fuashi et al. 2019). The use of dogs constitute a little less than 5% of animals killed followed by machetes and nets killing less than 1% of animals combined (Fuashi et al. 2019).

Hunting occurs during the day and at night. When going on day trips that are close to villages, hunters make the trip out to the forest and back within a single day. However, hunters also go on expeditions that can last from one or two nights to multiple weeks. When camping

overnight, hunters typically build small shelters, cutting down small trees or saplings from which to hang tarps for shelter. Oftentimes these shelters include smoking racks constructed in the center of the shelters. Sometimes hunters will establish a more permanent camp and repeatedly visit and use the same site, leaving the camp structure and few supplies (metal sheeting for smoking racks, cooking pots, etc). When hunting during the night, hunters primarily use headlamps requiring AA batteries. Spent batteries are often left on the ground and can also provide evidence of hunting activity.

Fuashi *et al.* (2019) found that within the Ebo forest region, blue and red duikers (*Cephalophus* spp. and *Cephalophus monticola* respectively) were the highest overall bushmeat offtake by biomass. Diurnal primates constituted the second highest overall biomass of animals hunted in the Ebo forest (Table 1.4). Guenons in particular comprised 68.2% of the total diurnal primate offtake with primate species listed by the IUCN Red List as Endangered constituting 31.7% of all primate bushmeat. Overall, the average weekly harvest rate was 2.87 animals hunted per day.

Primates are most often hunted using guns (Fa *et al.* 2005), but some can fall victim to snare traps. With many primates living in large social groups, hunters can easily shoot and kill multiple monkeys within a single shot (Wright & Priston, 2010). In addition, dogs are often used to locate primates, including drills in particular. Dogs will chase drills up trees and make them easier to shoot (Walther *et al.* 2002; Wright & Priston, 2010).

Ultimately, primates are severely threatened in this region due to hunting activities. When considering factors of income reliance, proximity to major bushmeat markets in Douala, efficient use of hunting methods, and the unprotected status of the Ebo-Makombe-Ndokbou forest block; the hunting of wildlife for bushmeat markets is a key open-access activity threatening the continued survival of primates in this region.

Table 1.4. The biomass (kg) of wildlife hunted over the course of 32 weeks within the Ebo forest. Data derived from Fuashi *et al.* 2019.

| Wildlife Hunted | Biomass (kg) |
|---|--------------|
| Ungulates (<i>Cephalophus</i> spp.) | 10,697 |
| Diurnal Primates | 5,631 |
| Red river hog (<i>Potamochoerus porcus</i>) | 4,239 |
| Rodents | 2,883 |
| Reptiles | 1,507.5 |
| Carnivores | 668 |
| Pangolins (<i>Manis</i> spp.) | 376.5 |
| Hyraxes (<i>Dendrohyrax</i> spp.) | 6.5 |

1.9.3 Commercial logging concessions and management

The Ebo-Ndokbou-Makombe forest region has been under commercial logging agreements since 2000 (Singer, 2008; Bureau Veritas Certification, 2012; Cerutti *et al.* 2015). To the north of the Ebo forest and overlapping over most of the Ndokbou forest is logging Forest Management Unit (FMU) 00-004 and community production forests, which are controlled and managed by local forest communities for sustainable harvesting of their designated local forest resources (WRI, 2011) (Figure 1.9). FMU 00-004 was officially allocated to PROPALM on Feb. 21, 2000 and then on July 24, 2004 the FMU was transferred to logging company Transformation Reef Cameroon (TRC) - a Dutch company, which has been operating in Cameroon since 1999 (Singer, 2008; Bureau Veritas Certification, 2012). The total area of FMU 00-004 was listed at 125,490 ha at the time of the signing agreement with TRC. However, areas near villages were taken out of this original area in order to increase agro-forestry area and limit “les conflits territoriaux” or territorial conflicts. The final area agreed upon was 102,000 ha . 50,060 ha were

identified as mature secondary forest, 41,080 ha dense moist evergreen forest, 4,587 ha young secondary forest, and 23,910 ha agricultural area (Bureau Veritas Certification, 2012).

FMUs are typically allocated for a period of 15 years (with a possible 5-year extension) and are awarded through a bidding process. Multiple FMUs may be managed by the same company, however a single logging company cannot manage more than 200,000 ha of FMUs (Gartlan, 1992; Cerutti et al. 2015). FMUs are broken down into smaller “concessions” (e.g. FMU 00-004 located north of Ebo Forest is designated as “concession 1029”) and within these concessions there may be additional areas divided into “assiette de coupes” (hereinafter referred to as “coupes”) usually comprising 2,500 ha parcels. Each individual coupe requires a full inventory, authorization, and permitting process in order to be logged. Coupes may remain open for three years but must be renewed annually with a fourth year often allowed (Gartlan, 1992). After a coupe is logged and closed, re-entry to harvest more timber is not allowed (Foahom, 2001). In addition, each coupe has a distinct boundary and no logging is permitted outside of the designated boundary if the logger does not have the proper permit for that coupe. The Cameroon Ministry of Forestry and Wildlife currently identifies 30 designated coupes within FMU 00-004, concession 1029 (Figure 1.10).

Logging companies can attain a Forestry Stewardship Council (FSC) certification, certifying that the company adheres to sustainable selective logging practices in an effort to sustain the forest’s biodiversity, productivity, and ecological processes (Auld et al. 2008; Singer, 2008; Morgan et al. 2011). This means that logging companies must adhere to specific harvesting requirements and the timber is closely tracked from the origin of the forest through the entire supply chain to guarantee that products meet these specific requirements. FSC certification includes requirements such as the 20/75% rule that states that the number of tree species selected to be logged must be more than 20 and their aggregated total volume must represent at least 75% of the total volume of trees inventoried in the FMU (Cerutti et al. 2011). In addition, companies must adhere to “annual allowable cuts” (AAC) and “regeneration rates” (RR), which is meant to

allow for guaranteed recovery of forests from one logging cycle to the next. Originally the RR stated that 100% of the harvested volume of all tree species must have a minimum cutting diameter (MCD). But in 2001 this ratio was reduced to 50% of the number of harvested trees of *each species* must be at the MCD. Depending on the FMU and condition of the proposed logging concession, FSC certifying bodies can require adaptations of these rules demanding stricter parameters to maintain sustainable harvests.

FSC certification was first granted in Cameroon in 2005 with TRC receiving FSC certification for logging in FMU 00-004 in 2008 (FSA certificate code BV-FM/COC-448849). The FSC certification report for TRC operating in FMU 00-004 available on public domain (fsc.force.com) states the specific conditions of timber harvesting that were to be upheld (Bureau Veritas Certification, 2012). The report identified that 36 species of trees were chosen to represent more than 75% of the total volume to be harvested with an MCD set at 70 cm. Within the 102,000 ha of available area in FMU 00-004, a total available volume of tree species for harvest was listed at 4,397,167 m³. The “Azobe” tree (*Lophostoma alata*) specifically comprised 229,753 m³ of this total volume.

The FMU 00-004 coupes permitted for harvesting in 2005 contained a total area of 4,183 ha with a volume of 80,573 m³ or 10,044 trees. Of this volume, 26,527 m³ comprised the Azobe tree and a reported 62% of the total volume comprised “concerne les essences aménagées” or species of management concern. The Azobe was by far the most abundant tree with a total of 3,356 trees inventoried. The next most abundant tree was “Ilomba” (*Pycnanthus angolensis*) with 906 total trees and a volume of 5,943 m³. A complete table comprising the number and volume of every tree species inventoried in the coupe is available in Appendix I. TRC says that it developed a low-impact forestry operating system in compliance with the “Regional code of exploitation low impact forest” (FAO, 2003) using felling techniques that would reduce the impact on the environment (Bureau Veritas Certification, 2012).

To allow for proper inventory and tracking of each individual tree harvested, a process of identification and recording was conducted in each logging area. Trees in the forest were painted with a single vertical red flash in order to identify the boundary of a coupe that the logging company was not supposed to breach. In addition to boundary tree markings, there were also markings from initial surveyors meant to identify possible trees for logging using the symbols “X” and/or “<” made using a machete. When a harvestable tree was officially identified a series of 2-3 letters for the tree species plus a number were painted in red on the trunk of the tree and this unique ID was recorded for inventory. In order to track each log harvested in compliance with FSC certification, the stump and base of the associated log of a cut tree received an imprint with a series of numbers indicating the following: (1) the tree ID created during inventory that was painted on the tree, (2) the assiette de coupe from which it came, (3) the FMU number, (4) a number assigned by the Ministry of energy and forestry, (4) the number of tree cut, and (5) the date the tree was cut.

Audits were conducted generally every two years beginning in 2007 to ensure the standards of FSC certification were being upheld by TRC in FMU 00-004. While each audit consistently listed a number of corrective actions that needed to take place, every audit conducted between 2007 and 2012 discussed issues revolving around TRC’s lack of response related to hunting, illegal logging, and habitat conservation concerns. Main issues from audits stated that the monitoring and analyzing of “High Value Forests for Conservation” (areas of the forest with plant and wildlife species of conservation concern) in the FMU and considerations of the bordering Ebo forest were not sufficiently taken into account by TRC. Corrective actions included effectively protecting the concession from illegal activities such as logging, but particularly poaching. The last audit conducted in 2012 indicated there were major issues not being adequately addressed by TRC to the FSC standard including complaints made by employees, poor living conditions in forest camps, and the cutting of unauthorized trees with large diameters. The end of the audit report stated that pending results of an additional audit after

TRC was to make the Corrective Action Requests, the company was to still retain its FSC certification. However, TRC's FSC certification is listed as terminated on January 25, 2013.

A report submitted in 2015 by the Food and Agriculture Organization (FAO) of the United Nations and the Center for International Forestry Research (CIFR) indicated FMU 00-004 was transferred in 2013 to logging company SIENCAM. The new procurement approved 94,917 ha of forest for logging at a price of 2,650 CFAs/ha (Cerutti et al. 2015). There is no indication via public domain that SIENCAM (also SEFECCAM) was FSC certified at the time of the FMU 00-004 procurement or if it is currently FSC certified. Based on cut stump number imprints identified within the Ndokbou forest during this study, the most recent active logging occurred within FMU 00-004 in 2017.

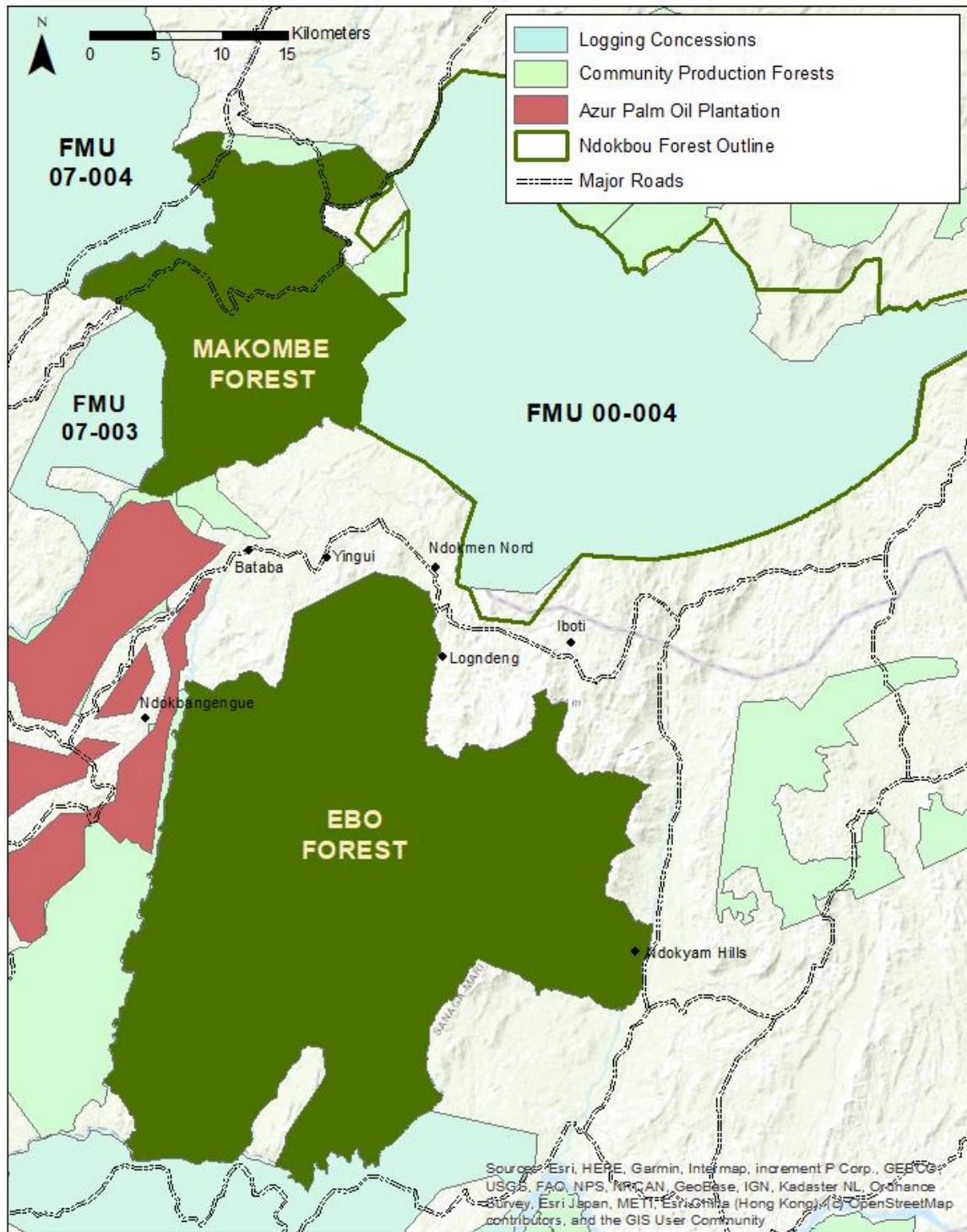


Figure 1.9. The location of commercial logging Forest Management Units (FMUs), community production forests, and the Azur palm oil plantation located near the Ebo-Makombe-Ndokbou forest block.

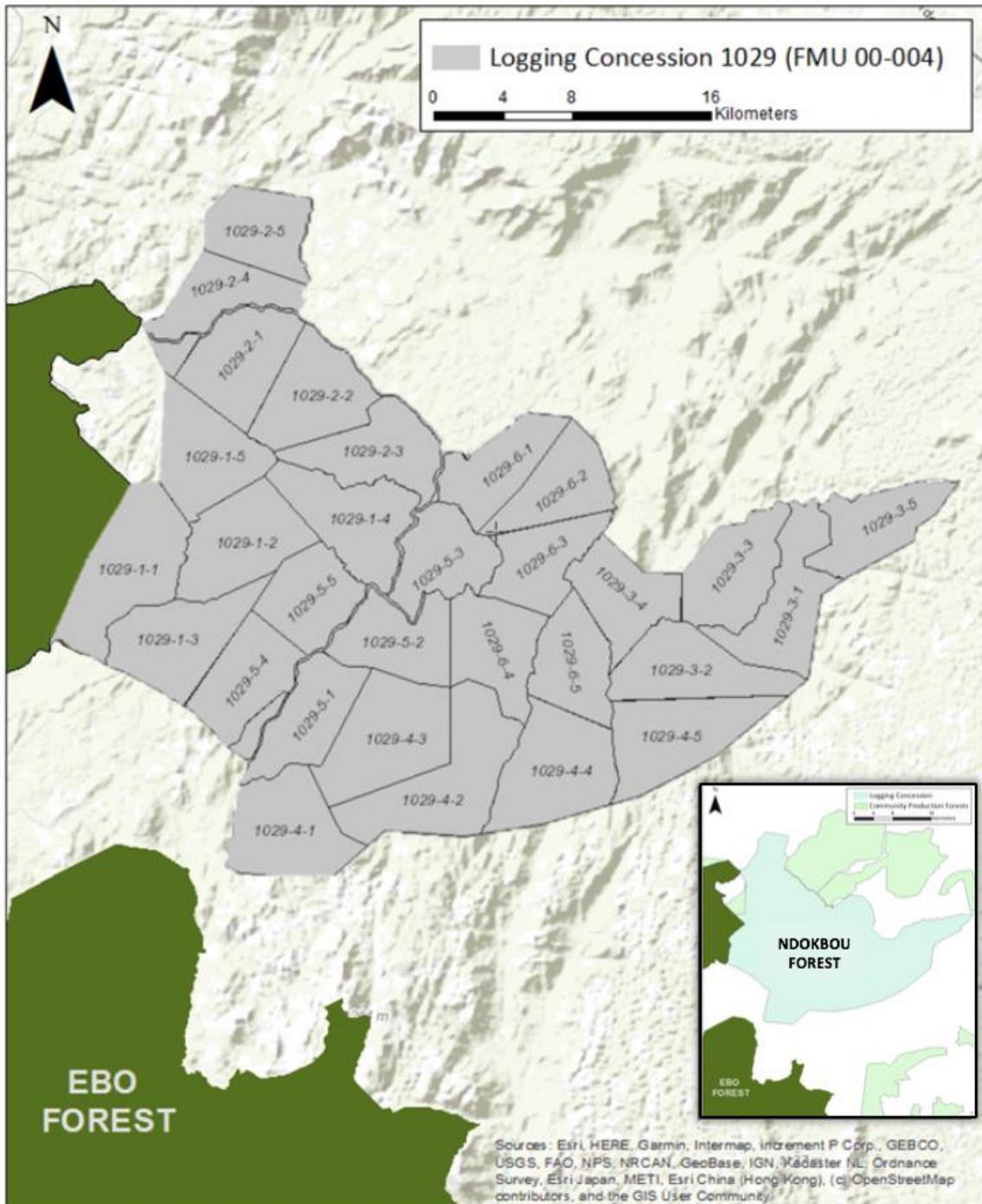


Figure 1.10. Logging FMU 00-004, concession 1029 broken down into designated ~2,500 ha assiette de coupe parcels (parcel boundary data obtained from the Cameroon Ministry of Forestry and Wildlife, <https://cmr.forest-atlas.org/map?l=en>).

1.9.4 Logging impacts

While FMU 00-004 currently has no active logging operations, the evidence and impacts from 15 years of intermittent logging operations still remain. Gravel roads, bridges over streams and rivers, large open areas cut out of the forest and paved with gravel for loading logs onto trucks, and camps from surveyors and/or loggers are left behind in the forest from logging operations. Logging roads in varying conditions remain intact, fragmenting habitat, creating forest edges, and allowing easy access for hunters into previously hard to reach areas of the forest. The most recent logging activity occurred in 2017/2018 in the northern region of the Ndokbou forest and one of the main logging roads made the forest accessible via motorbike for hunting activity. While many logging bridges have been destroyed in an attempt to deter hunters, they can often still access and use the roads on foot.

In addition to ease of access for hunting due to the presence of logging roads, habitat degradation from logging activities can occur. Roads and loading areas create gaps in the forest and forest edges leading to changes to microclimates, vegetation and soil composition, and subsequent loss of biodiversity (Laurance et al. 2009; Baker et al. 2016; Betts et al. 2017). In addition, when roads and loading areas begin growing back with vegetation, natural secondary forest succession occurs, changing the habitat dynamics of the forest; homogenization of plant species, often weedy and fast colonizing plants dominate secondary forest succession (Wright, 2005). Some studies estimate that secondary tropical forests won't recover wildlife species diversity for 20-40 years (Dunn, 2004; Wright, 2005). However, there are also studies indicating that over time, some primate species that prefer secondary forests exhibit stable or even higher encounter rates in lightly-logged forests (Remis & Jost Robinson, 2012; Chapman et al. 2018).

FMU 00-004 conducted selective logging practices (in comparison to the practice of clear-cutting) to maintain FSC certification, however some of the most sought after tree species are most utilized by some of the most endangered primate species in this region. TRC documented that it was primarily focusing its production on harvesting the Azobe tree (*Lophira*

alata) (Singer, 2008; Bureau Veritas Certification, 2012). This is a critical tree species used as a primary food source by the Preuss's red colobus as they prefer eating young leaves from the *L. alata* tree (Oates, 2011). Another important tree species, *Erythrophleum ivorensis*, or the "Tali" tree is also an important food source for Preuss's red colobus with observations of *P. preussi* often feeding on *E. ivorensis* leaves in this region (A. Parfaitt, pers. comm.). McGraw *et al* (2016) also reported the red colobus species *P. badius* feeding on *E. ivorensis* in the Ivory Coast's Tai National Park. TRC reported that within the coupes harvested in 2005, of the 80,857m³ available tree volume, Tali trees comprised 2,783 m³ or 323 trees. Overall, Tali tree harvesting throughout Cameroon increased from 20% to 31% of all timber exports between 2010 and 2015 (Cerutti et al. 2015). In fact, while logging exports have increased in Cameroon, the number of tree species being exported fell from 52 in 2010 to 27 in 2015 with the same 5-6 tree species accounting for 70% of the total log exports (Cerutti et al. 2015). This highlights an immense decrease in diversification of selective logging pressures.

Specifically in regard to red colobus species overall, logging operations have impacted food availability, parasite infections, demographic variation, and overall stress levels (Struhsaker et al. 2004; Bonnell et al. 2010; Chapman et al. 2013). Chapman *et al.* (2013) found in Kibale National Park, Uganda that red colobus population declines were correlated with declines in food availability and increased parasite infections associated with forest fragments. They also found that stress levels (measured by cortisol) were 3.5 times greater in red colobus groups inhabiting forest fragments compared with those in Kibale National Park, indicating red colobus in forest fragments were unhealthy and physiologically stressed. Struhsaker *et al* (2004) found that red colobus groups in Udzungwa, Tanzania were smaller in forests heavily degraded from human activities compared with red colobus in large, mature blocks of forest. Other research has similarly found that red colobus group size in heavily logged areas are significantly smaller than those in mature, intact forests (Chapman et al. 2002; Marshall et al. 2004). Ultimately, logging

operations that lead to habitat degradation and fragmentation have shown to impact red colobus health, stress, and group size leading to overall population declines.

Overall, primates' response to logging activities and associated habitat alterations may vary by primate species due to diet preference, home range size, and body size (Wolfe et al. 2005). A study conducted by Chapman *et al.* (2000) analyzing primate abundance in habitats with varying logging pressures over the course of 28 years found that while most primate species showed slight abundance increases over time, there were species that never recovered, even decades after logging. Long-term effects on primate populations may not yet be as evident, short-term logging effects including human presence and the use of loud machinery can cause displacement of entire primate groups leading to changes in foraging and social behavior (Wolfe et al. 2005).

1.10 Thesis Structure

This thesis is organized into four main chapters in order to assess the population status of and threats to Preuss's red colobus and other diurnal primates in the Ndokbou forest. In chapter two, I examine how and why primate species richness and relative abundance vary in different parts of the Ndokbou forest. This chapter also compares estimates of primate relative abundance in Ndokbou to those from Korup National Park.

In chapter three I assess the geographic extent and frequency of hunting and logging activities in the Ndokbou forest. First I review hunting sign encounter frequency and distribution identified by forest survey methods with a specific emphasis on gun hunting sign encounters, as gun hunting is the primary method used for hunting primates. I then make comparisons of hunting sign encounters with geographic variables including distance to villages and roads, terrain ruggedness, elevation, and slope. Next I compare gun hunting frequency and distribution estimates with estimates identified by passive acoustic monitoring methods where I also review temporal patterns of gun hunting including hourly, daily, weekly, monthly, and seasonal patterns.

Finally, I compare hunting frequency estimates from forest surveys and acoustic data with that of Korup National Park.

Chapter four synthesizes findings from chapters two and three into an integrated conclusion aimed at assessing the effects of hunting and logging activities on primate distribution and abundance in the Ndokbou forest. First I review and summarize key findings from chapters two and three. I then analyze synergistic effects of both logging and hunting activities and review how the interplay of these two activities may be contributing to my observed patterns of primate distribution and abundance. I conclude with a discussion of the conservation implications of my findings for the Ebo-Makombe-Ndokbou forest block.

Chapter 2: The population status of Preuss's red colobus and other diurnal primates in the Makombe-Ndokbou forests

2.1 Introduction

The Ebo (1,400 km²), Makombe (600 km²), and Ndokbou (~ 1,000 km²) forests located in the Littoral region of southwest Cameroon, fall within the Gulf of Guinea rainforest region, identified as a biodiversity hotspot known for tremendous levels of species richness and diversity among plants and animals (Oates et al. 2004). The Ebo-Makombe-Ndokbou forest block is especially important for primate diversity as a number of rare and endangered primate species are endemic to this region. These include the Critically Endangered Nigeria-Cameroon chimpanzee (*Pan troglodytes ellioti*), an unidentified subspecies of the Western gorilla (*Gorilla gorilla*), and Preuss's red colobus (*Piliocolobus preussi*) (Morgan et al. 2011).

While once more widespread in the forests between Nigeria's Cross River and Cameroon's Sanaga River, Preuss's red colobus' current geographic range is now fragmented into two isolated clusters: one comprising a population in Korup National Park (KNP), Cameroon and across the border in the eastern portion of the Oban Division of Cross River National Park (CRNP), Nigeria, and the other cluster in the Ebo-Makombe-Ndokbou forest block.

Most of the current population data available on the extent, abundance, and conservation status of Preuss's red colobus has been provided through systematic ecological and anthropological research in KNP (Waltert et al. 2002; Linder, 2008; Fonkwo et al. 2015, Hofner et al. 2018), however little is known about the distribution, abundance, and conservation status of Preuss's red colobus within the Ebo-Makombe-Ndokbou forests.

Within this region, the Ebo forest has received the most research and monitoring efforts to date with wildlife and human impact studies intermittently occurring within the past two decades (Dowsett-Lemaire & Dowsett, 2001; Morgan et al. 2003; Whytock & Morgan, 2010a, 2010b; Whytock et al. 2014; Cheek et al. 2018; Mahmoud et al. 2019; Abwe et al. 2019, 2020). Most of

the recent research has focused on monitoring and studying the behavioral ecology of the Nigeria-Cameroon chimpanzee (*Pan troglodytes ellioti*) and gorilla (*Gorilla gorilla*) in the Ebo forest (Dowsett-Lemaire & Dowsett, 2001; Morgan et al. 2003, 2011; Morgan & Abwe, 2006; Abwe et al. 2019, 2020). Extremely limited survey efforts and data are available for the Makombe and Ndokbou forests or on the distribution and abundance of the Critically Endangered Preuss's red colobus in this region.

Prior to 2018, the Makombe and Ndokbou forests had not received any systematic wildlife survey efforts since Dowsett-Lemaire & Dowsett (2001) surveyed regions of the Ebo-Makombe-Ndokbou forest block for primates between 2000 and 2001. While mainly focusing their survey efforts on *G. gorilla*, they indicated that hunters sighted populations of Preuss's red colobus in the Mt. Sinai region of the Ndokbou forest. While surveying the Ndokbou forest, Dowstt-Lemaire & Dowsett never personally observed *P. preussi*, but they did have direct sightings in the northwest region of the Makombe forest. They also acknowledged that *P. preussi* populations were decreasing in all forest regions due to over-hunting. Their study did identify large numbers of the Endangered drill (*M. leucophaeus*) and Preuss's guenon (*Allochrocebus preussi*) found in the Ndokbou forest.

The most recent survey efforts in the Ndokbou forest were conducted in June and July of 2018. While these survey efforts confirmed the continued presence of many primate species including *P. t. ellioti*, *M. leucophaeus*, *A. preussi*, and *C. torquatus*, no statistical analysis or evaluation of the survey data have been conducted in order to estimate relative abundance. In addition, the presence of *P. preussi* was not able to be confirmed in the Ndokbou forest during these most recent surveys.

With scarce ecological and primate monitoring data available for the Ndokbou forest, it is difficult to determine if Preuss's red colobus still inhabits this forest and to understand how hunting and logging have affected the diurnal primate community. I therefore conducted systematic primate surveys in various parts of the Ndokbou forest, including the forest around Mt. Sinai, in order to

evaluate the most recent reports of the presence of red colobus in the Ndokbou forest. The data collected from these surveys were used to address the following questions and predictions:

1. How do species richness and the relative abundance of diurnal primate species vary among different areas of the Ndokbou forest?

Predictions:

- a. Based on reports from 2018 primate surveys, Preuss's red colobus will exhibit the lowest primate encounter frequency in the Ndokbou forest
- b. Primate encounter frequencies will increase as distances from roads and villages increases
- c. Primate encounter frequencies will increase as terrain ruggedness increases
- d. Primate encounter frequencies will increase as slope increases

2. How does the relative abundance of primate species in the Ndokbou forest compare to that of the Makombe forest and Korup National Park ?

Predictions:

- a. Primate encounter frequencies will be similar to those of the nearby unprotected Makombe forest
- b. Primate encounter frequencies will be lower than those of the protected Korup National Park

With only reports of sightings available for primate species found in the Ndokbou forest, this is the first study to establish relative abundance and distribution estimates for primate species found in this region of the Ebo-Makombe-Ndokbou forest region. Following 2018 surveys in search of Preuss's red colobus, this study focuses survey efforts specifically on assessing the population status of the Critically Endangered Preuss's red colobus monkey in the Ebo-Makombe-Ndokbou forest. The most recent documented sighting of Preuss's red colobus occurred in the Ebo forest in 2012 (E. Abwe pers. comm). Reports from local hunters identify the

presence of Preuss's red colobus in the Ndokbou forest, however, there are no documented encounters from the most recent forest surveys conducted in 2001 (Dowsett-Lemaire & Dowsett, 2001) and 2018 in the Ndokbou forest.

2.2 Methods

2.2.1 Forest reconnaissance surveys

I conducted forest reconnaissance "recce" surveys in the Ndokbou forest of the Ebomakombe-Ndokbou forest block to collect primate abundance and distribution data between October 15th and December 19th, 2019. Recce surveys were utilized for data collection because this method bypasses the time-consuming and often inefficient process for the alternative line transect survey method (Walsh & White, 1999). During recce surveys, researchers maintain a chosen compass bearing and follow this general direction while walking a path of least resistance along natural features and already existent trails. In contrast, line transect surveys require following a straight line, resulting in time consuming efforts to cut paths through dense forest vegetation. In addition, hunters may use the line transects, which apart from providing easy access to regions of the forest for hunting activities, could also influence detection probabilities for both primates and hunting signs (Buckland et al. 2010). Similar to line transect surveys, during recce surveys researchers collect data from wildlife sightings in order to estimate relative abundance and distribution (Plumptre et al. 2013). However, during recce surveying researchers do not need to estimate sighting distances as is required for line transect surveys, which also results in less effort for data collection (Walsh & White, 1999).

Sources of bias may exist with recce surveys because certain vegetation types may be avoided (i.e. dense vegetation) restricting representation of the study area. Recce surveys may also rely on existing paths, such as hunting trails, that certain wildlife species may purposefully avoid (Linder, 2008). However, some terrestrial species actually prefer traveling along the same areas of least resistance. Walsh & White (1999) found that recce survey data correlated with line

transect survey data on gorilla nests and elephant dung. I concluded that recce surveys were most appropriate for this study due to the rugged terrain and steep elevation gradients in the Ndokbou forest. Recce surveys could help increase the total survey distance covered and subsequently the opportunity for wildlife sightings.

2.2.2 Data collection

I overlaid a grid of 4 km x 4 km cells on a map of a portion of the Ndokbou forest (Figure 2.1) and conducted recce surveys within designated grid cells. I established a temporary basecamp within each grid cell from which I conducted recce surveys. My average start time for surveys was 06:46 with an average survey speed of .92 km/hours and a mean survey distance of 8.13 km. Any delays in start time were due to illness or injury. I began and ended recce surveys at the basecamp as loops in the general directions of NW, SW, SE, and NE corners of each grid (Figure 2.2). Recce surveys that strayed from these general directions or the average survey distance were due to maneuvering impassable terrain (i.e. cliffs ledges, large rock faces, etc.) and large rivers. Table 2.1 shows the distance, time, and survey speed parameters for each recce survey completed.

During each recce survey I recorded all primate signs including direct sightings and indirect encounters, which included vocalizations, nests, dung, and feeding signs in a waterproof notebook and I recorded their location using a Garmin 64st GPS. Due to high hunting intensity in the Ndokbou forest, primates often react to human presence by becoming cryptic and/or fleeing. Therefore, I walked all surveys quietly and slowly with frequent stops to scan the forest.

For each primate group sighting, I recorded the time at which the sighting occurred along with the species sighted, the number of individuals, and whether or not any vocalizations were heard. For indirect encounters, primate species identification was only possible when indirect encounters included vocalizations. While feedings signs could be narrowed down to certain species, primate identification via vocalizations was most accurate. I recorded *P. t. ellioti* nest

encounters during surveys by identifying the number of nests of the same age class that were located in the same general vicinity (no farther than approximately 20 m from one another) as one single nest encounter (Kouakou et al. 2009). Moreover, I defined a *P. t. ellioti* nest encounter as one or more individual nests of the same age class within 20 m from one another.

G. gorilla, which are confirmed in the Ebo forest, also make nests. Without the presence of dung or hair accompanying nest encounters, it is difficult to distinguish between *P. t. ellioti* and *G. gorilla* nests (Sanz et al. 2007). Based on nest identification criteria established by Tutin & Fernandez (1984) and nest characterizations made by Abwe (2018) in the Ebo forest, *G. gorilla* nests are most commonly found on the ground and in secondary forests. However, no formal confirmation of the presence of *G. gorilla* in the Ndokbou forest has ever been made. For the purpose of this study, a special note was taken when ground nests were encountered, but without further evidence of dung or hair present, it was assumed that all nest encounters were *P. t. ellioti*.

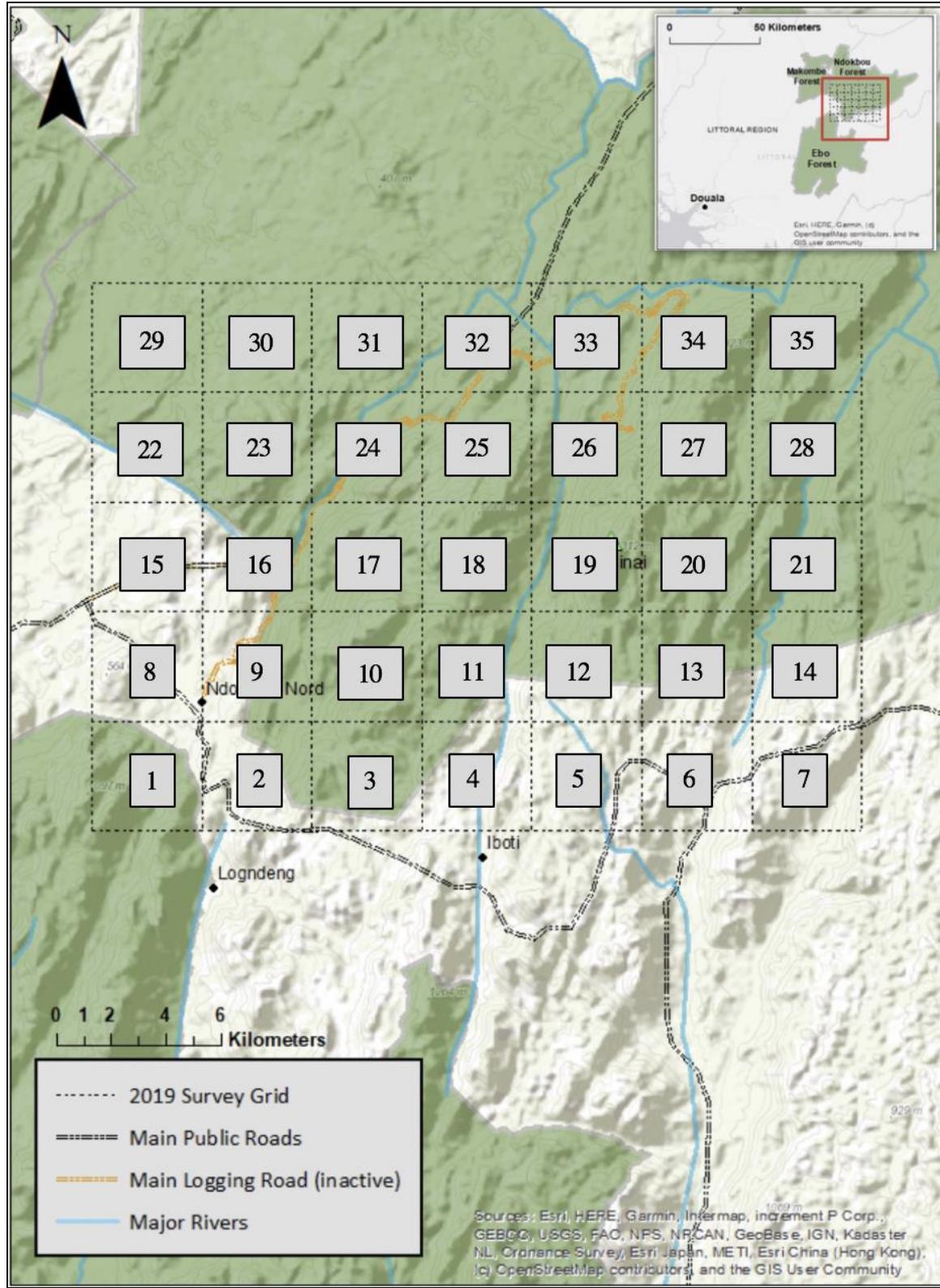


Figure 2.1. Grid, with 4 km x 4 km cells (grid cell ID numbers in gray boxes), overlaid on the Ndokbou forest for designating areas of the forest to complete recce surveys.

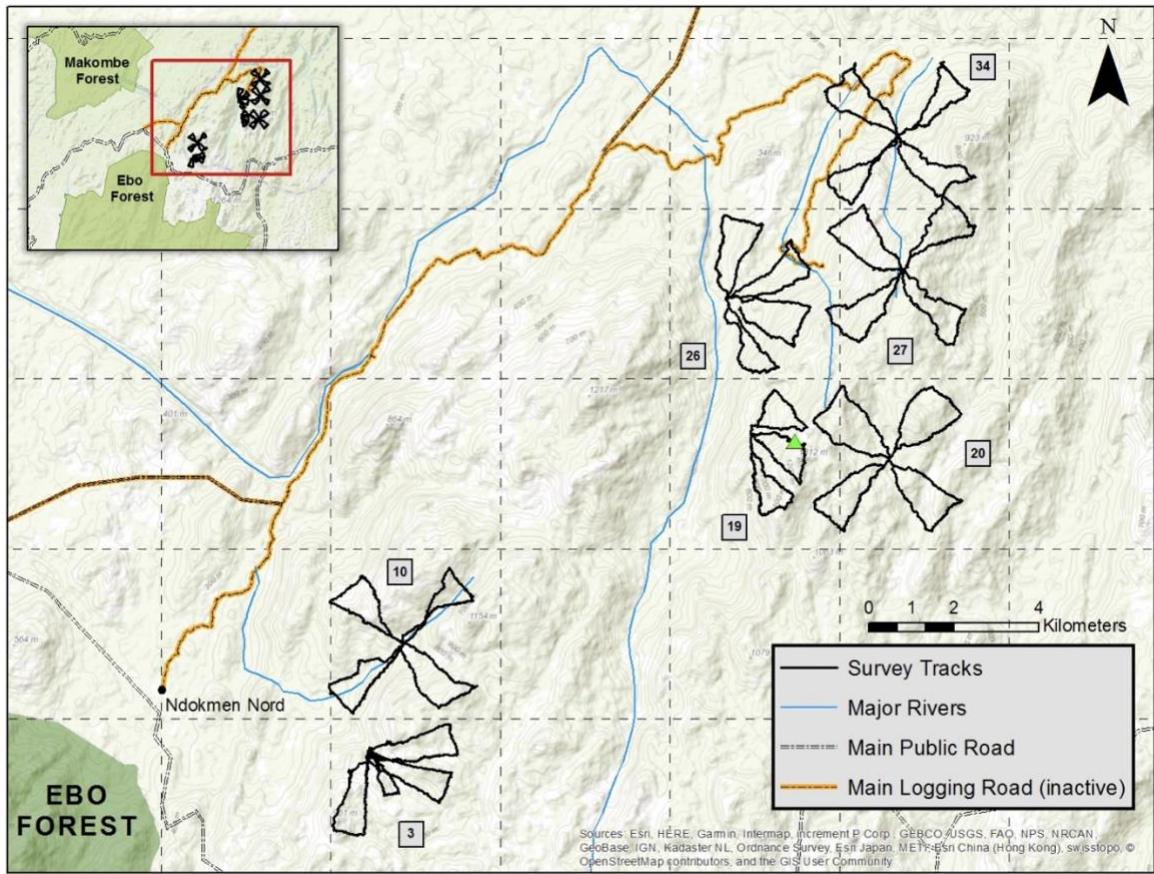


Figure 2.2. The location and GPS track of each recce survey completed in 2019 in grids 3, 10, 19, 20, 26, 27, and 34 (grid numbers indicated in corresponding boxes) in the Ndokbou forest.

Table 2.1. Grid location, survey distance (km), and time parameters for each recce survey conducted during 2019 in the Ndokbou forest.

| Grid Number | Survey Direction | Survey Distance (km) | Survey Date (mm/dd/yy) | Start Time | Survey speed (km/hour) |
|-------------------------------------|-------------------------|-----------------------------|-------------------------------|-------------------|-------------------------------|
| 3 | NE | 8.18 | 12/16/19 | 06:49 | .95 |
| | E | 8.55 | 12/17/19 | 06:39 | .91 |
| | SE | 4.58 | 12/18/19 | 06:41 | .83 |
| | S | 8.08 | 12/19/19 | 06:41 | .75 |
| Grid 3 Total Survey Effort: | | 29.38 | | | |
| 10 | NE | 8.66 | 12/11/19 | 06:55 | .99 |
| | SE | 8.95 | 12/12/19 | 06:47 | .97 |
| | SW | 8.55 | 12/13/19 | 06:42 | .85 |
| | NW | 9.17 | 12/14/19 | 06:38 | .98 |
| Grid 10 Total Survey Effort: | | 35.33 | | | |
| 19 | N | 6.35 | 11/30/19 | 06:49 | .93 |
| | E | 7.92 | 12/1/19 | 06:31 | 1.11 |
| | SE | 8.27 | 12/02/19 | 06:40 | .99 |
| Grid 19 Total Survey Effort: | | 22.53 | | | |
| 20 | NE | 8.5 | 11/19/19 | 07:38 | 1.04 |
| | SE | 8.09 | 11/20/19 | 07:06 | 1.01 |
| | SW | 8.12 | 11/21/19 | 06:49 | .97 |
| | NW | 8.2 | 11/22/19 | 06:43 | .86 |
| Grid 20 Total Survey Effort: | | 32.92 | | | |
| 26 | N | 7.13 | 11/25/19 | 06:46 | .95 |
| | NE | 7.88 | 11/26/19 | 06:50 | .86 |
| | E | 7.99 | 11/27/19 | 06:38 | .86 |
| | S | 7.54 | 11/28/19 | 06:42 | .92 |
| Gird 26 Total Survey Effort: | | 30.54 | | | |
| 27 | NE | 8.83 | 10/15/19 | 06:54 | .77 |
| | SE | 7.88 | 10/16/19 | 06:57 | .82 |
| | SW | 8.73 | 10/17/19 | 06:38 | .82 |
| | NW | 7.92 | 10/18/19 | 06:33 | .85 |
| Grid 27 Total Survey Effort: | | 33.36 | | | |
| 34 | NE | 8.67 | 10/20/19 | 06:38 | 1.04 |
| | SE | 9.04 | 10/21/19 | 06:48 | .89 |
| | SW | 8.87 | 10/22/19 | 06:42 | .97 |
| | NW | 8.81 | 10/23/19 | 06:38 | 1.02 |
| Grid 34 Total Survey Effort: | | 35.39 | | | |
| Overall Total Survey Effort: | | 219.45 | | | |

2.2.3 Data analysis: primate relative abundance

I exclusively used sighting frequencies and vocalization encounter frequencies to assess primate relative abundance rather than attempting to estimate absolute population densities. In forests with historically high levels of hunting there are issues with accurately calculating absolute densities of primate populations due to small sample sizes and cryptic behavioral tendencies in response to humans (Linder, 2008; Buckland et al. 2010). The use of recce survey methods allows for an evaluation of primate populations using encounter rates to establish a relative abundance estimate (Linder, 2008; Plumptre et al. 2013). Encounter rates are measured by the number of encounters per unit in survey effort, measured in time or distance and then used to calculate a mean encounter rate (Linder, 2008). While this method is not useful for calculating population numbers, it can be used to assess abundance trends and to compare relative abundance between survey locations. I calculated primate group sighting frequency as the number of sighting encounters (primate groups and primate individuals) divided by the distance surveyed (km). I also calculated encounter frequency by combining direct sightings with indirect vocalization encounters.

For overall primate sighting frequencies and encounter frequency estimates, I first compare results from my 2019 surveys to previous recce surveys conducted in the Ndokbou forest by trained field assistants during June and July of 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan). Those field assistants previously conducted surveys in Korup National Park and in the Ebo forest and accompanied me on my first forest outing so that I could ensure that I was employing the same recce survey methods and data collection parameters to remove any sources of bias. The 2018 recce surveys were also conducted within similar regions of the Ndokbou forest that I conducted recce surveys (Figure 2.3). See Table 2.2 for details on the 2018 surveys, including the distances surveyed and the overall combined 2018 and 2019 survey effort in the Ndokbou forest.

The Shapiro-Wilk test for normality indicated non-normal distributions of sighting frequency and encounter frequency data so I used the non-parametric Kruskal-Wallis test with a significance level of 0.05 to test differences in sighting frequency and encounter frequency estimates between each primate species. I only included *P. t. ellioti* vocalization encounter estimates in species encounter frequency comparison analyses and conducted a separate analysis reviewing the frequency and geographic distribution of nest encounters. I conducted all statistical analyses using R Studio (v. 3.6.2).

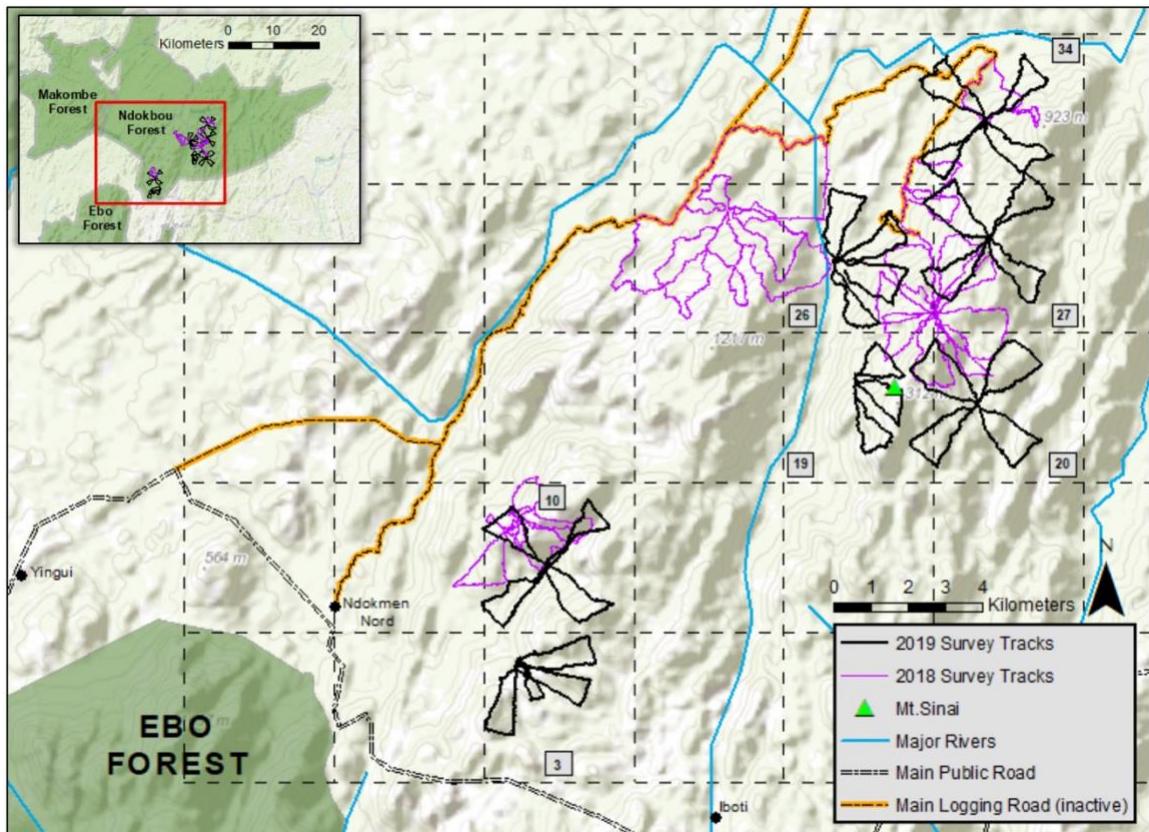


Figure 2.3. The location of recce surveys conducted in the Ndokbou forest in 2018 compared to the recce survey locations conducted for this study in 2019.

Table 2.2. Recce surveys conducted in 2018 in the Ndokbou forest (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) with total survey distances (km) and combined 2018 and 2019 overall survey effort.

| 2018 Survey Month | Survey | Survey Distance (km) |
|--|---------------|-----------------------------|
| June | 1 | 5.56 |
| | 2 | 9.71 |
| | 3 | 11.52 |
| | 4 | 5.43 |
| | 5 | 3.59 |
| | 6 | 7.15 |
| | 7 | 13.39 |
| | 8 | 12.61 |
| | 9 | 10.71 |
| | 10 | 9.11 |
| | 11 | 7.7 |
| | 12 | 3.65 |
| | 13 | 8.31 |
| June Total Survey Effort: | | 108.44 |
| July | 1 | 10.04 |
| | 2 | 6.14 |
| | 3 | 4.66 |
| | 4 | 8.86 |
| | 5 | 6.69 |
| | 6 | 7.49 |
| | 7 | 8.29 |
| | 8 | 6.93 |
| | 9 | 9.67 |
| | 10 | 9.63 |
| | 11 | 8.56 |
| | 12 | 7.1 |
| July Total Survey Effort: | | 94.06 |
| Overall 2018 Survey Effort: | | 202.50 |
| Combined 2018 and 2019 Survey Effort: | | 421.96 |

2.2.4 Data analysis: primate geographic distribution

I plotted the geographic distribution for each primate species on a map of the Ndokou forest using 2019 survey data. I also conducted analysis of geographic distribution of primate populations by calculating average sighting frequency and encounter frequency (sightings and vocalizations) estimates for each grid surveyed in 2019. I then compared these averages between survey grid locations using the non-parametric Kruskal-Wallis test. The sample size of primate sightings and vocalization encounters within each grid were not large enough to conduct any statistical analysis comparing species-specific sighting and encounter frequencies between each survey grid. I analyzed primate species composition of each survey grid by reviewing the percentage of sightings and encounters each primate species represented in each grid.

I also obtained geographic and terrain variables for each primate encounter point (sightings and vocalizations) collected from survey data in 2018 and 2019. I conducted all GIS analyses using ArcMap 10.6.1. I obtained the elevation from primate encounter point GPS data recorded during surveys. Using the Point Distance tool in ArcMap I measured the distance from the nearest village and the nearest main road to each primate encounter point. I distinguished between main public roads, which are accessible via motorbike and main logging roads (inactive) which have road blocks making them inaccessible to motorbikes but still accessible via walking. I derived slope from a 90 m digital elevation model (DEM) base layer of the region using the Slope tool in the Spatial Analyst tools in ArcMap. I obtained the original SRTM 90 m DEM layer from the CGIAR-Consortium for Spatial Information open portal (<http://srtm.cgiar.org/srtmdata/>) and I re-sampled the 90 m layer to obtain smaller cell sizes using nearest neighbor sampling for a final DEM raster using cell sizes of approximately .004° x 004° (~ 443 m x 443 m) and spatial resolution of 1:0.012°.

I measured the ruggedness of the terrain of each primate encounter point using a tool derived from Sappington *et al.* (2007) to calculate a Vector Ruggedness Measure (VRM) in ArcMap. Using slope and aspect (orientation of a slope), VRM captures variability from the

combination of these measures in a single raster cell for a measure of terrain ruggedness.

Moreover, VRM distinguishes a smooth steep hillside from an irregular hillside that varies in slope and aspect so that VRM values are low in both flat areas and smooth steep areas, but high in areas that are both steep and rugged. This ruggedness index is in comparison to the traditional Terrain Rugged Index (TRI) often derived from Riley *et al.* (1999). TRI uses the sum of changes in elevation so that values are low in flat areas but high in areas that are steep and in areas that are steep and rugged (Figure 2.4). However, this method does not directly measure the variability in topographic aspect and gradient and does not clearly distinguish steep, even terrain (high slope and low ruggedness) from steep terrain that is uneven and broken (high slope and high ruggedness). Ultimately, an area that is steep and rugged would have a similar TRI value as an area that was just simply steep but not rugged. With consideration of the ruggedness of the terrain and constant changes in slope and aspect of rock faces and hillsides, particularly in and surrounding the Mt. Sinai region of the Ndokbou forest during forest surveys, I wanted to utilize a ruggedness index that would adequately distinguish a rugged slope from simply a steep slope. Using the VRM tool, I created a raster masked by the elevation raster (to keep consistent cell sizes) to measure a VRM index for each raster cell in the Ndokbou forest. I then used the extract values by point tool to obtain VRM values for the location of each primate encounter point.

In addition to elevation, slope, and VRM indices, I evaluated primate encounter points by estimating a terrain parameter that incorporated elevation into the VRM index. I took the VRM values obtained for each primate encounter point and multiplied the elevation value at which the encounter points were recorded. So with this index value, a primate encounter with a low value would indicate both low elevation and low VRM, while an encounter containing a large value would indicate high elevation and high VRM. This index is different from both VRM and TRI in that neither of those indices incorporate elevation into ruggedness or slope. While they both use *changes* in elevation to estimate the degree of slope, neither distinguishes a steep slope/ruggedness at high elevation from a steep slope/ruggedness at a low elevation. I wanted to

add the additional variable of elevation to the VRM values because in my experience in the Ndokbou forest, rough terrain (and presumably high VRM values) were present at both high and low elevations however, higher elevations indicated more difficult access to the forest versus lower elevations. And so by incorporating the value of elevation to the VRM score, this would effectively incorporate terrain roughness with elevation.

In order to evaluate any effects of these geographic/environmental variables on primate encounters, I conducted a principal component analysis (PCA) in R using each of the geographic variables described above. I used the PCA analysis to show any influence that elevation, slope, distance to roads, distance to villages, or terrain ruggedness may have on the species of primate encountered in the Ndokbou forest.

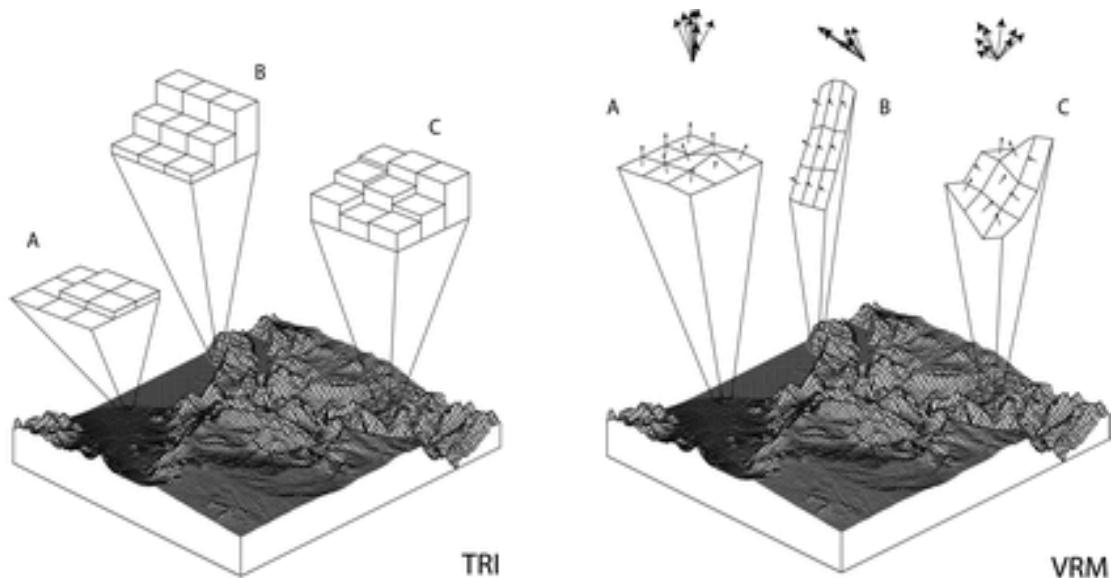


Figure 2.4. Terrain ruggedness analysis using Terrain Rugged Index (TRI) vs. Vector Ruggedness Measure (VRM). In regard to TRI, **A** (flat terrain) would result in a low TRI value, while **B** (steep terrain) and **C** (steep and rugged terrain) would both result in similar TRI values. In regard to VRM, **A** (flat terrain) and **B** (steep, smooth terrain) would result in low VRM values and **C** (steep and rugged terrain) would result in high VRM values. (derived from Sappington *et al.* 2007).

2.3 Results

2.3.1 Primate species richness

Of the ten diurnal primate species found in the Ebo-Makombe-Ndokbou forests, eight species were directly sighted during recce surveys from the combined 2018 and 2019 survey data. There were no sightings of *P. preussi*, although vocalizations of this species were heard on one survey route (Grid cell 19). There were also no encounters (sightings or indirect) of *G. gorilla* in the Ndokbou forest.

In regards to species richness distribution, the minimum number of primate species I encountered in 2019 survey grids was five. The largest number of primate species I encountered were in grid 26 with seven total species encountered (sightings and vocalization encounters). I also encountered the largest number of large-bodied species (*P. t. ellioti*, *M. leucophaeus*, *C. torquatus*, and *A. preussi*) except for *P. preussi* in grid 26. Overall, *C. nictitans* and *C. p. pogonias* were the most encountered primate species with encounters in all seven survey grids. Figure 2.5 displays the distribution of all primate species encounters in 2019 (sightings and indirect).

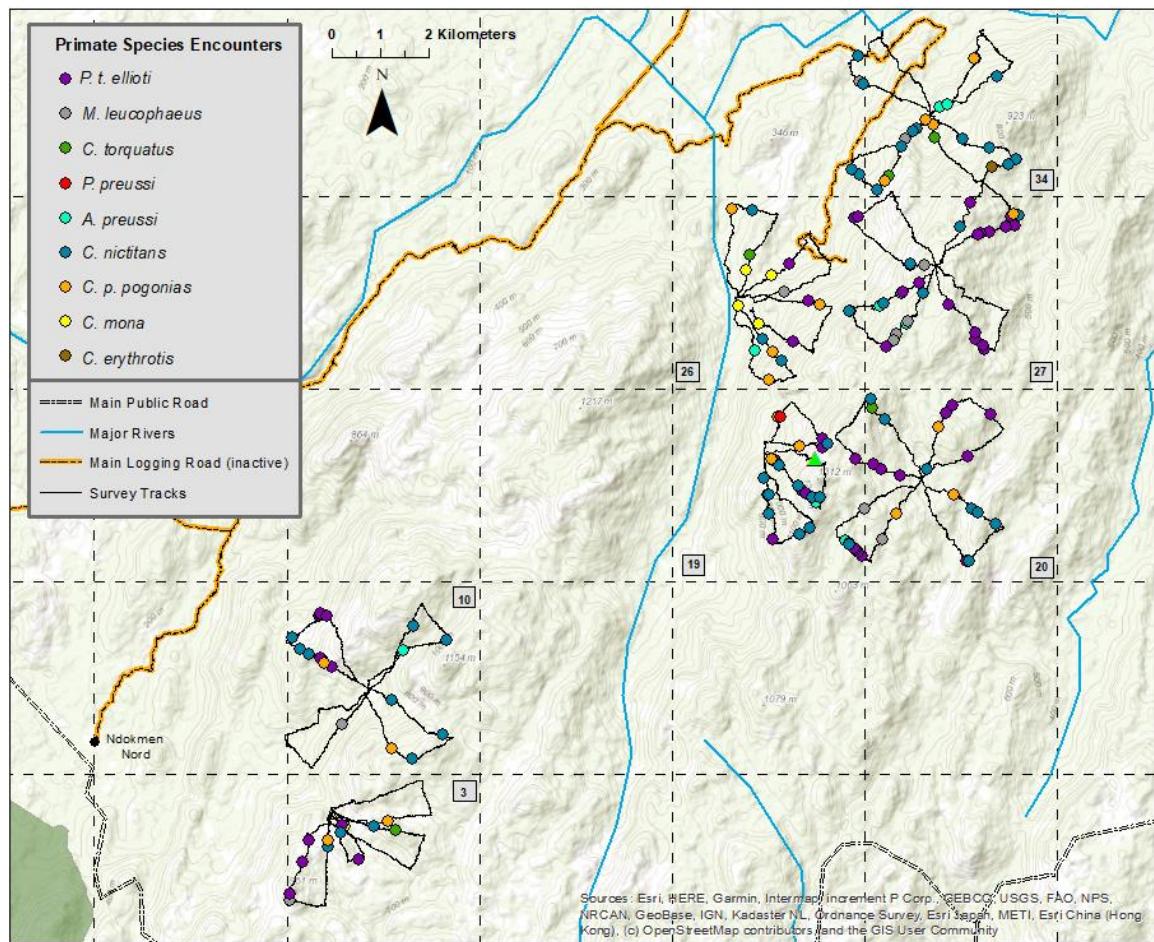


Figure 2.5. The distribution of primate species encounters within each 2019 survey grid with reference to grid numbers in gray boxes.

2.3.2 Primate sighting frequency

During 2018 surveys, a total of 56 primate sighting encounters occurred over a total survey distance of 202.50 km resulting in a mean sighting frequency of 0.28 groups/km (S.E. = 0.08). During 2019 surveys, I encountered a total of 34 primate sightings over a total survey distance of 214.45 km resulting in a mean primate sighting frequency of 0.15 groups/km (S.E. = 0.04). There was no significant difference in overall mean primate sighting frequency between survey years (Mann-Whitney U, $W = 353.50$, $p\text{-value} = 0.77$). Table 2.3 shows the sighting frequency of each primate species between survey years. There was no significant difference of species' sighting frequencies between years except for the sighting frequency of *C. erythrotis*.

During 2018, *C. erythrotis* was sighted significantly more than during 2019 surveys (Mann-Whitney U, W = 432, p-value = 0.004).

Table 2.3. Primate species' sighting frequencies (groups/km) during 2018 and 2019 surveys with total number of sightings indicated in parentheses. * Indicates significant difference between years.

| | 2018 Sighting Frequency | Standard error | 2019 Sighting Frequency | Standard error |
|---|--------------------------------|----------------|--------------------------------|----------------|
| <i>P.t.elliotti</i> | 0.01 (2) | 0.006 | 0.00 (0) | N/A |
| <i>M. leucophaeus</i> | 0.005 (1) | 0.005 | 0.009 (2) | 0.005 |
| <i>C. torquatus</i> | 0.01 (3) | 0.009 | 0.00 (0) | N/A |
| <i>P. preussi</i> | 0.00 (0) | N/A | 0.00 (0) | N/A |
| <i>A. preussi</i> | 0.02 (5) | 0.01 | 0.02 (5) | 0.007 |
| <i>C. nictitans</i> | 0.11 (22) | 0.04 | 0.09 (19) | 0.03 |
| <i>C. mona</i> | 0.02 (4) | 0.01 | 0.009 (2) | 0.006 |
| <i>C. p. pogonias</i> | 0.04 (10) | 0.02 | 0.03 (6) | 0.02 |
| <i>C. erythrotis</i> * | 0.04 (9) | 0.02 | 0.00 (0) | N/A |
| Overall Primate Sighting Frequency | 0.28 (56) | 0.08 | 0.15 (34) | 0.04 |

From the combined 2018 and 2019 survey data, a total of 90 primate groups were sighted over a combined survey distance of 421.95 km. The resulting mean primate sighting frequency for the Ndokbou forest was 0.21 groups/km (S.E. = 0.04). Sighting frequency was significantly different across species (Kruskal-Wallis, $X^2 = 65.58$, df = 8, $p < 0.001$). *C. nictitans* was sighted significantly more than any other species. Sighting frequencies were lowest for *P. t. elliotti*, *M. leucophaeus*, and *C. torquatus*. There were also no sightings of *P. preussi* (Table 2.4).

When I reviewed the geographic distribution of primate sighting frequencies using only 2019 survey data, overall primate sighting frequency was not significantly different among survey grids (Kruskal-Wallis, $X^2 = 6.05$, df = 6, p = 0.42) (Figure 2.6). However, grids 19 and 34 had more than double the overall primate sighting frequency than all other grids surveyed in 2019 (Table 2.5). When reviewing the primate species composition of sightings in grids 19 and 34, *C. nictitans* and *C. p. pogonias* together comprised 86% and 92% of all sightings in these grids respectively. And overall, *C. nictitans* comprised the largest percentage of sightings in five out of seven survey grids (Figure 2.7). I sighted *A. preussi* in five out of seven of the survey grids, which made this species the most abundant of all larger-bodied species and the most widespread species after *C. nictitans*. However, *A. preussi* often comprised the smallest percentage of sightings in the grids in which it was sighted.

Table 2.4 Overall mean sighting frequencies (groups/km) for each primate species encountered in the Ndokou forest. Sighting frequency was calculated by combining 2018 and 2019 survey data.

| | IUCN Conservation Status | No. of Sightings | Sighting Frequency | Standard error |
|-----------------------|--------------------------|------------------|--------------------|----------------|
| <i>P. t. ellioti</i> | Endangered | 2 | 0.004 | 0.003 |
| <i>M. leucophaeus</i> | Endangered | 3 | 0.007 | 0.004 |
| <i>C. torquatus</i> | Endangered | 3 | 0.006 | 0.004 |
| <i>P. preussi</i> | Critically Endangered | 0 | 0 | N/A |
| <i>A. preussi</i> | Endangered | 10 | 0.02 | 0.007 |
| <i>C. nictitans</i> | Near Threatened | 41 | 0.09 | 0.02 |
| <i>C. mona</i> | Least Concern | 6 | 0.02 | 0.007 |
| <i>C. p. pogonias</i> | Vulnerable | 16 | 0.04 | 0.01 |
| <i>C. erythrotis</i> | Vulnerable | 9 | 0.02 | 0.009 |

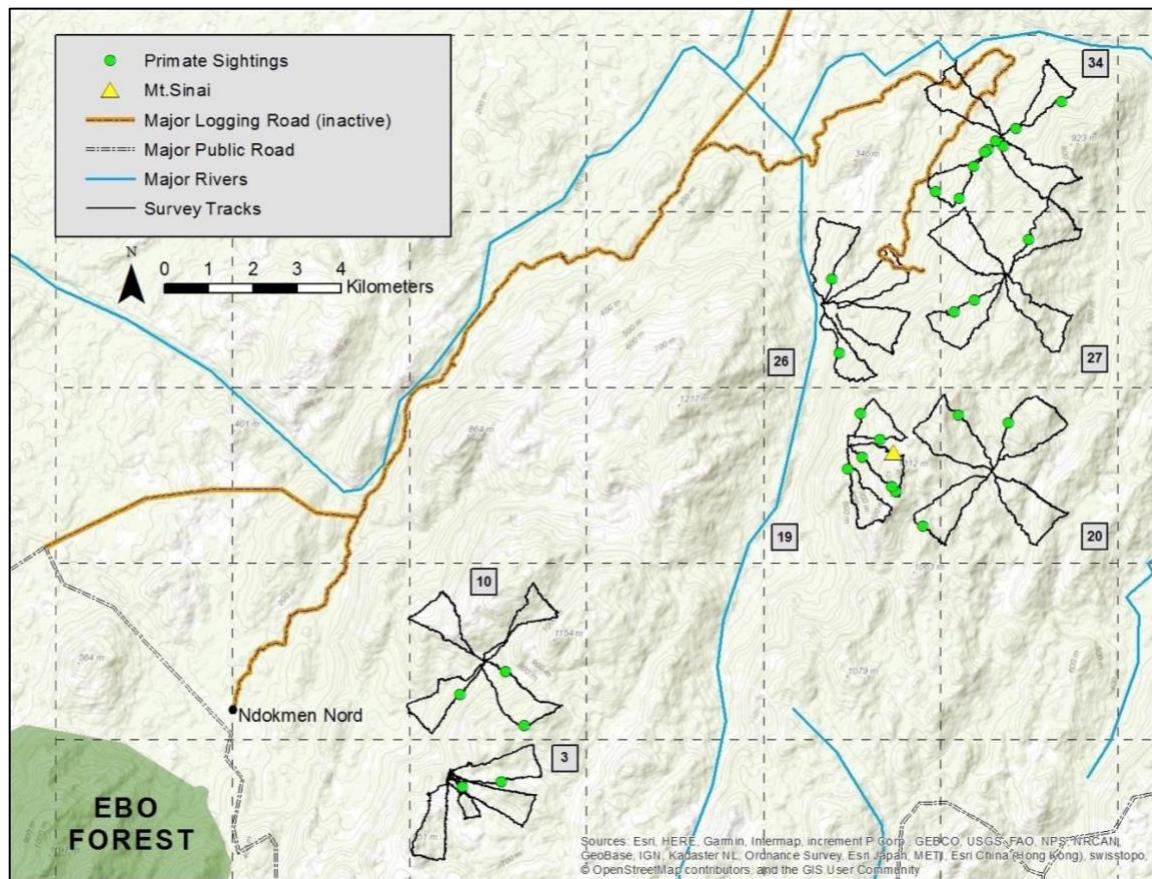


Figure 2.6. Geographic distribution of every primate sighting encounter point during 2019 surveys in the Ndokbou forest with reference to grid numbers in gray boxes.

Table 2.5. Overall mean primate sighting frequency (groups/km) for each grid surveyed during 2019 surveys in the Ndokbou forest.

| | Grid # | | | | | | |
|-------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | 3 | 10 | 19 | 20 | 26 | 27 | 34 |
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of sightings | 3 | 4 | 7 | 3 | 2 | 3 | 12 |
| Primate Sighting Freq. | 0.10 | 0.11 | 0.31 | 0.09 | 0.07 | 0.09 | 0.34 |
| Standard error | 0.07 | 0.05 | 0.10 | 0.03 | 0.04 | 0.05 | 0.19 |

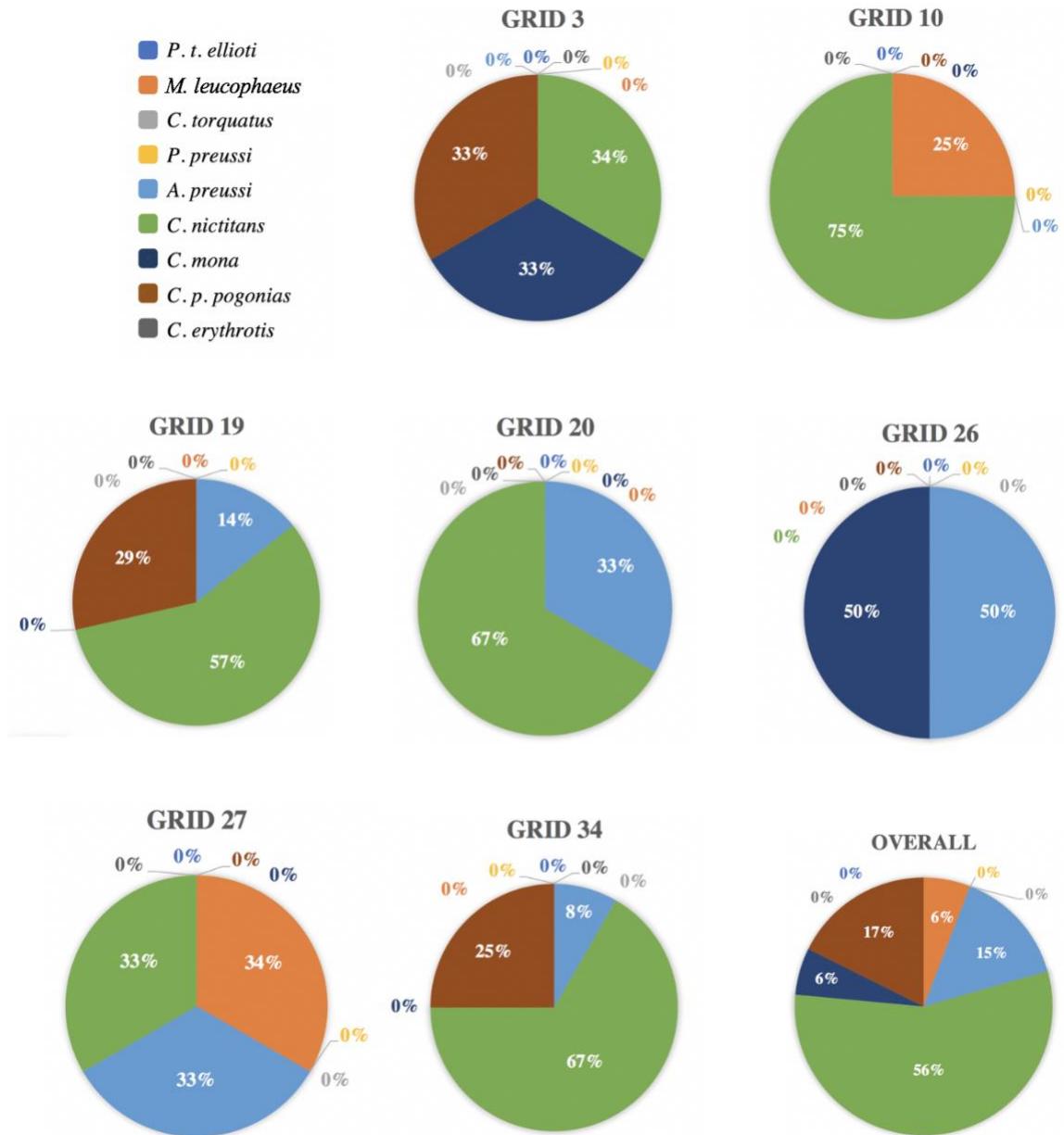


Figure 2.7. The percentage of each primate species sighted in each 2019 survey grid and overall for all grid surveys combined.

2.3.3 Primate encounter frequency

Surveys in 2018 recorded 73 encounters of primate calls and 56 sightings of primate groups resulting in a mean primate encounter frequency (combined vocalization and sighting encounters) of 0.64 groups/km (S.E. = 0.10). During 2019 surveys, I encountered a total of 89 primate vocalizations and 34 primate sightings resulting in a mean primate encounter frequency (vocalizations and sightings) of 0.56 groups/km (S.E. = 0.07). There was no significant difference in overall mean primate encounter frequency between survey years (Mann-Whitney U, W = 373, p-value = 0.52). In addition, there was no significant difference for each primate species' encounter frequency between survey years except for *C. erythrotis*. Surveys in 2018 found significantly more encounters of *C. erythrotis* than 2019 surveys (Mann-Whitney U, W = 464, p-value = 0.001). (Table 2.6).

Table 2.6. Primate species' encounter frequencies (groups/km) during 2018 and 2019 surveys with total number of encounters indicated in parentheses. Encounter frequency was calculated by combining sighting encounters and vocalization encounters. *Indicates significant difference between years.

| | 2018 Encounter Frequency | Standard error | 2019 Encounter Frequency | Standard error |
|--|---------------------------------|-----------------------|---------------------------------|-----------------------|
| <i>P.t.elliotti</i> | 0.02 (5) | 0.01 | 0.02 (5) | 0.01 |
| <i>M. leucophaeus</i> | 0.005 (1) | 0.005 | 0.03 (7) | 0.01 |
| <i>C. torquatus</i> | 0.05 (11) | 0.02 | 0.07 (14) | 0.01 |
| <i>P. preussi</i> | 0.00 (0) | N/A | 0.005 (1) | 0.006 |
| <i>A. preussi</i> | 0.04 (8) | 0.01 | 0.04 (9) | 0.02 |
| <i>C. nictitans</i> | 0.31 (63) | 0.05 | 0.28 (61) | 0.04 |
| <i>C. mona</i> | 0.03 (6) | 0.01 | 0.02 (4) | 0.01 |
| <i>C. p. pogonias</i> | 0.11 (23) | 0.03 | 0.10 (21) | 0.02 |
| <i>C. erythrotis</i> * | 0.06 (12) | 0.02 | 0.005 (1) | 0.004 |
| Overall Primate Encounter Frequency | 0.64 (129) | 0.10 | 0.56 (123) | 0.07 |

From the combined 2018 and 2019 survey data, a total of 252 primate encounters (vocalizations and sightings) occurred. The resulting mean primate encounter frequency for the Ndokbou forest was 0.60 groups/km (S.E. = 0.06). Primate encounter frequencies were significantly different across species (Kruskal-Wallis, $X^2 = 159.96$, df = 8, p-value < 0.001). *C. nictitans* exhibited a significantly larger encounter frequency than all other primate species. *C. p. pogonias* had the next largest encounter frequency with a significantly greater frequency than all other primate species apart from *C. nictitans*. and *C. torquatus*. *P. preussi* exhibited the lowest encounter frequency (Table 2.7).

When I reviewed the geographic distribution of primate encounter frequencies using only 2019 survey data, primate encounter frequencies compared between survey grids were not significantly different (Kruskal-Wallis, $X^2 = 10.23$, df = 6, p-value = 0.12). While not statistically significant, grids 19 and 34 exhibited the highest overall primate encounter frequency, with grids 3 and 27 exhibiting the lowest (Table 2.8). When reviewing the primate species composition of encounter frequencies in each survey grid, *C. nictitans* and *C. p. pogonias* were the only primate species encountered in every survey grid (Figure 2.8). And overall, *Cercopithecus* spp. and *C. nictitans* in particular comprised the largest percentages of encounters in every survey grid. Larger-bodied primate species were encountered in every survey grid, however, they comprised the smallest percentages of encounters. And in regard to grids 19 and 34, which contained the largest primate encounter frequencies, *Cercopithecus* spp. comprised a combined total of 74% and 71% of all primate encounters in these grids respectively. Due to the small number of species-specific encounters for each grid, I did not conduct any statistical tests comparing the encounter frequencies of species within each grid.

Table 2.7. Overall mean encounter frequency (groups/km) for each primate species encountered in the Ndokbou forest. Encounter frequency was calculated by combining sighting encounters and vocalization encounters pooled from 2018 and 2019 survey data.

| | IUCN Conservation Status | No. of Encounters | Encounter Frequency | Standard error |
|-----------------------|--------------------------|-------------------|---------------------|----------------|
| <i>P. t. ellioti</i> | Endangered | 10 | 0.02 | 0.009 |
| <i>M. leucophaeus</i> | Endangered | 8 | 0.02 | 0.007 |
| <i>C. torquatus</i> | Endangered | 25 | 0.06 | 0.01 |
| <i>P. preussi</i> | Critically Endangered | 1 | 0.002 | 0.003 |
| <i>A. preussi</i> | Endangered | 17 | 0.04 | 0.01 |
| <i>C. nictitans</i> | Near Threatened | 124 | 0.29 | 0.03 |
| <i>C. mona</i> | Least Concern | 10 | 0.02 | 0.008 |
| <i>C. p. pogonias</i> | Vulnerable | 44 | 0.10 | 0.02 |
| <i>C. erythrotis</i> | Vulnerable | 13 | 0.03 | 0.01 |

Table 2.8. Overall mean encounter frequency (groups/km) for each grid surveyed during 2019 surveys in the Ndokbou forest.

| | Grid # | | | | | | |
|------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | 3 | 10 | 19 | 20 | 26 | 27 | 34 |
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of encounters | 9 | 17 | 19 | 21 | 13 | 13 | 31 |
| Overall encounter frequency | 0.31 | 0.48 | 0.80 | 0.64 | 0.43 | 0.39 | 0.88 |
| Standard error | 0.05 | 0.17 | 0.10 | 0.17 | 0.15 | 0.20 | 0.19 |

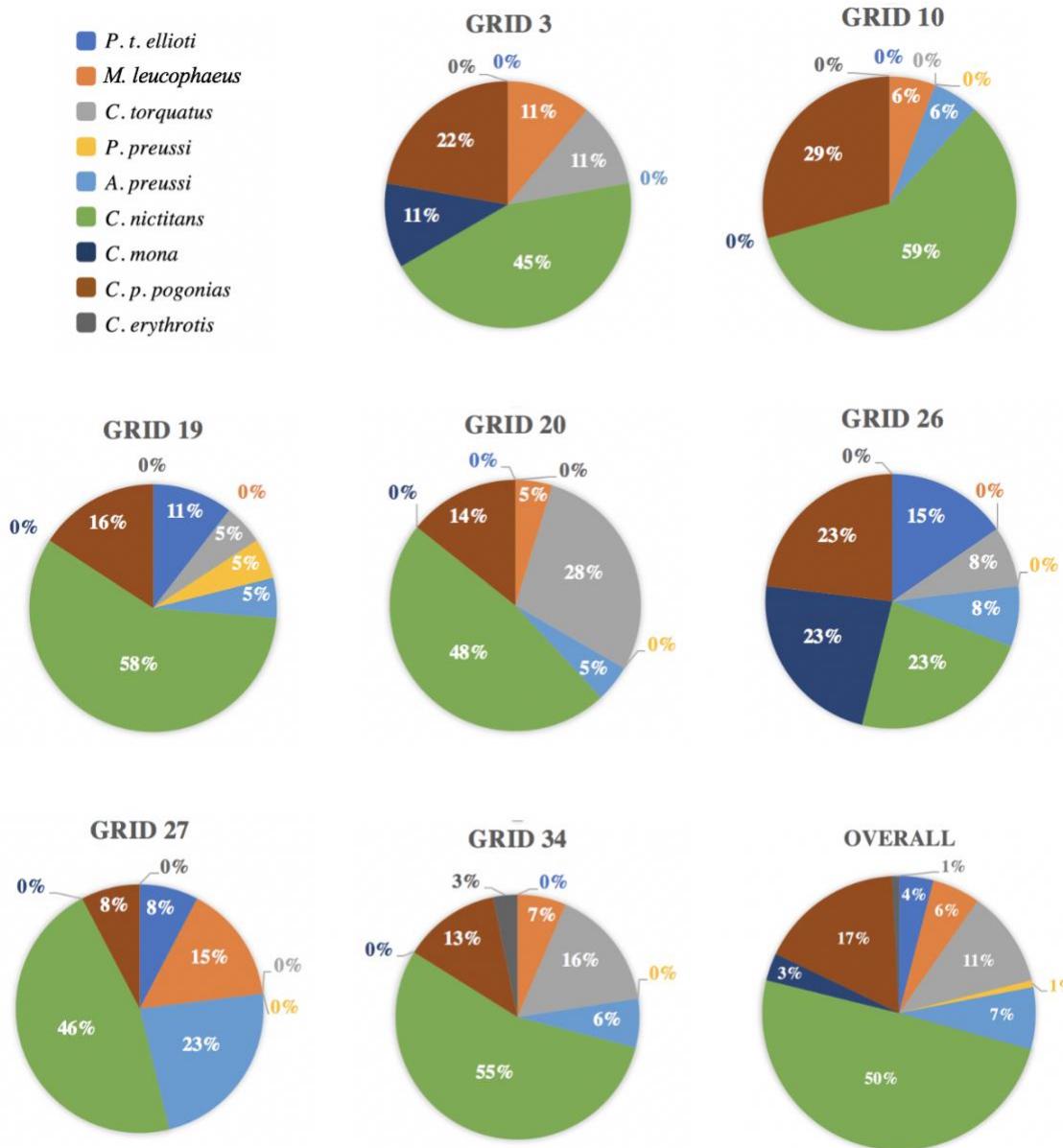


Figure 2.8. The percentage of each primate species encountered (combined vocalization and sighting encounters) in each 2019 survey grid and overall for all grid surveys combined.

I encountered a total of 39 *P. t. ellioti* nest groups during 2019 surveys comprising a total of 142 individual nests. Overall nest group size ranged from 1 to 46 nests with an overall average nesting group size of 3.62 (S.E. = 1.18). All nests were arboreal with the exception of one ground nest found among three arboreal nests encountered in grid 3. This was the only ground nest encounter during surveys. I encountered *P. t. ellioti* nests in every survey grid except for grids 34 and 26 (Figure 2.9). Table 2.9 displays nest group encounter data for each survey grid.

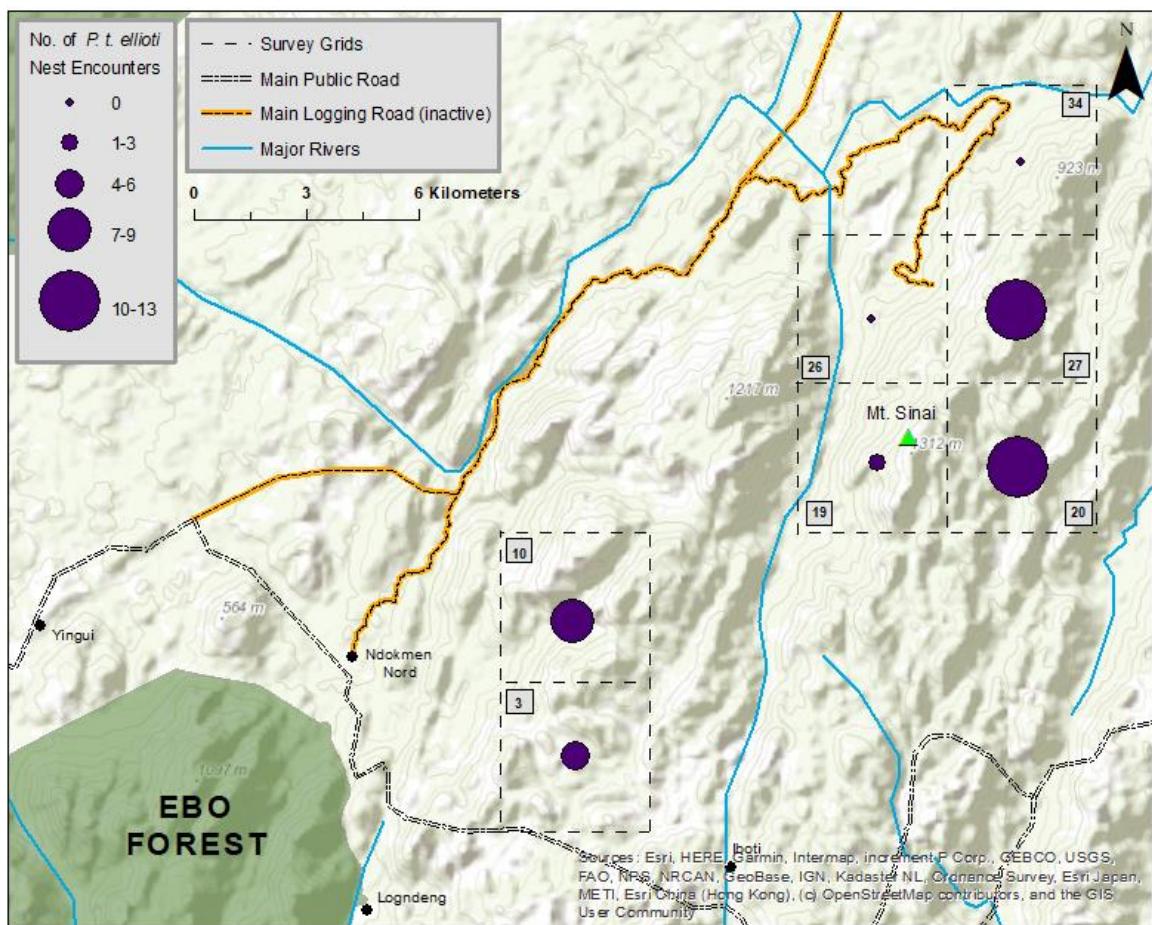


Figure 2.9. *P. t. ellioti* nest encounter totals for each 2019 survey grid with reference to survey grid numbers in gray boxes.

Table 2.9. The total number of *P. t. ellioti* nest encounters for each 2019 survey grid including total number of individual nests, minimum, maximum, and average nest group size.

| Survey Grid | Total # of nest group encounters | Total # of individual nests | Min. nest group size | Max. nest group size | Avg. nest group size | Standard error |
|-------------|----------------------------------|-----------------------------|----------------------|----------------------|----------------------|----------------|
| 3 | 5 | 19 | 2 | 11 | 4.75 | 2.13 |
| 10 | 7 | 63 | 1 | 46 | 9.0 | 6.29 |
| 19 | 3 | 7 | 1 | 3 | 2.33 | 0.67 |
| 20 | 11 | 19 | 1 | 4 | 1.73 | 0.36 |
| 26 | 0 | - | - | - | - | - |
| 27 | 13 | 34 | 1 | 8 | 2.62 | 0.62 |
| 34 | 0 | - | - | - | - | - |

2.3.4 Primate encounter geographic variables: distance to villages and roads

The closest distance a 2018 or 2019 recce survey occurred to a main public road, accessible by motorbike (as depicted in Figure 2.10), was 1.18 km with the greatest distance being 16.84 km. This indicates that the possible range of distance in which a primate could have been encountered was 1.18 – 16.84 km. The overall average distance a primate was encountered (sighted or vocalizations encountered) from the nearest main public road was 9.96 km (S.E. = 0.18). When comparing the average distance to the nearest public road, there was no significant difference across species (Kruskal-Wallis, $X^2 = 11.32$, df = 7, p-value = 0.13). However, *A. preussi* had the highest overall average distance with *P.t. ellioti* exhibiting the lowest average distance (Table 2.10). *A. preussi* also had the greatest minimum distance to public roads with *M. leucophaeus* exhibiting the greatest range of distances and *C. nictitans* having the next greatest range of distances from public roads. Table 2.10 displays the average distance to the nearest public road for each species including the minimum and maximum distances at which species were encountered. *P. preussi* is not included in this analysis because there was only one

encounter and computing an average was not possible. But the single *P. preussi* encounter occurred 13.04 km from the nearest village and 3.36 km from the nearest logging road.

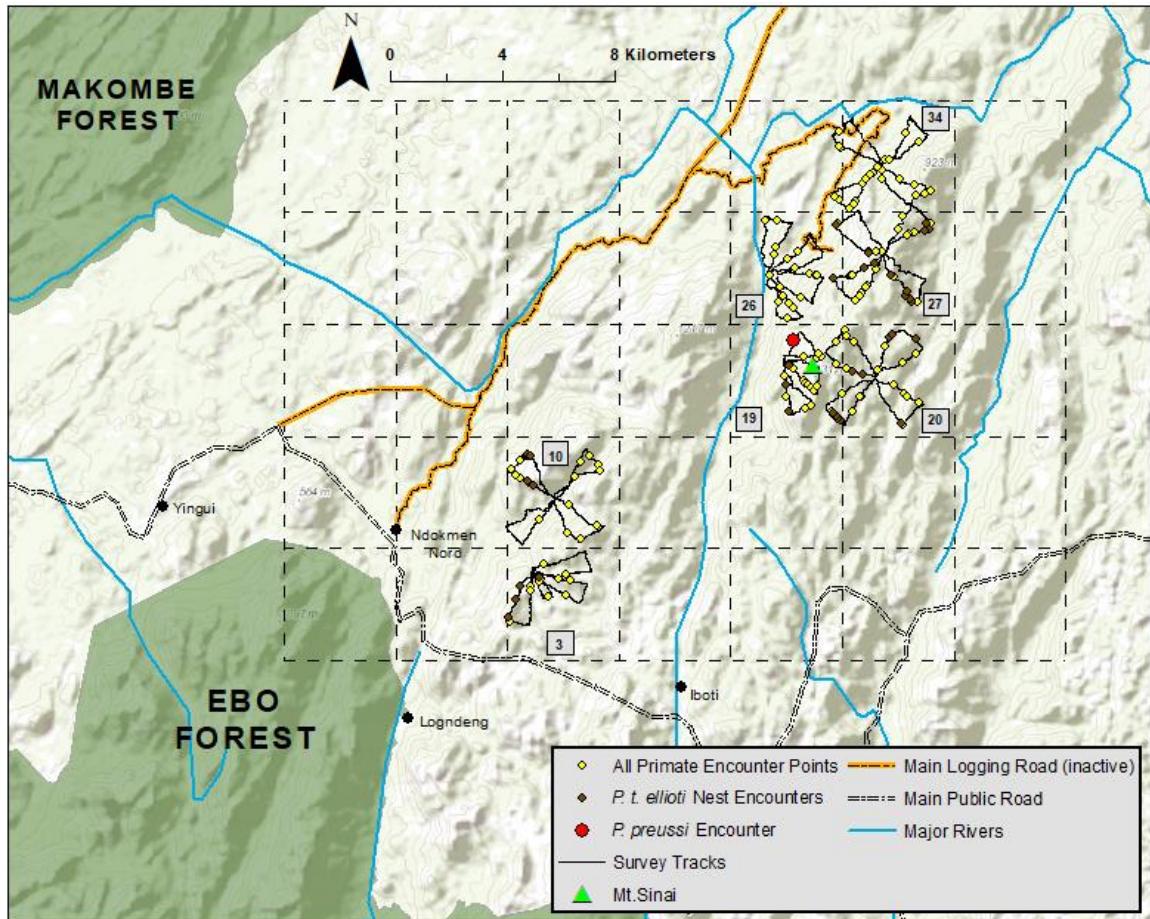


Figure 2.10. Geographic distribution of every primate encounter point (sighting and indirect encounters) with *P. t. ellioti* nest encounters and the location of the *P. preussi* encounter (Lat: 4.574743°, Long: 10.493658°) during 2019 surveys in the Ndokbou forest with reference to grid numbers in gray boxes.

Table 2.10. The minimum, maximum, and average distance (km) for each primate species encountered (direct and indirect encounters) from the nearest main public road found in the Ndokou forest. Data were combined from 2018 and 2019 recce surveys.

| | Minimum Distance | Maximum Distance | Average Distance | Standard Error |
|-----------------------|------------------|------------------|------------------|----------------|
| <i>P. t. ellioti</i> | 1.48 | 14.94 | 9.26 | 0.28 |
| <i>M. leucophaeus</i> | 1.33 | 15.80 | 10.10 | 0.67 |
| <i>C. torquatus</i> | 3.16 | 15.85 | 10.44 | 0.75 |
| <i>P. preussi</i> | N/A | N/A | N/A | N/A |
| <i>A. preussi</i> | 6.29 | 15.16 | 11.21 | 0.69 |
| <i>C. nictitans</i> | 2.43 | 16.32 | 10.14 | 0.33 |
| <i>C. mona</i> | 2.91 | 14.03 | 10.41 | 1.31 |
| <i>C. p. pogonias</i> | 2.56 | 15.85 | 10.30 | 0.69 |
| <i>C. erythrotis</i> | 5.35 | 14.03 | 10.52 | 0.98 |

When comparing distances to the nearest inactive logging roads, which are impassable for motorbikes, but still accessible by walking, the possible range in which primate encounters could have occurred based on locations of recce surveys was 0.00 - 6.78 km. Overall the average distance primate encounters occurred to logging roads was 2.54 km (S.E. = 0.09). When comparing distances between species, there was no significant difference using a 0.05 significance level (Kruskal-Wallis, $X^2 = 12.41$, df = 7, p-value = 0.09). *C. torquatus* exhibited the largest average distance from logging roads, while *A. preussi* had the lowest average (Table 2.11). *P.t. ellioti* had the largest maximum distance from logging roads and *C.p. pogonias* and *C. nictitans* had the lowest minimum distances.

Table 2.11. The minimum, maximum, and average distance (km) for each primate species encountered (direct and indirect encounters) from the nearest main logging road (inactive) found in the Ndokbou forest. Data were combined from 2018 and 2019 recce surveys.

| | Minimum Distance | Maximum Distance | Average Distance | Standard Error |
|-----------------------|------------------|------------------|------------------|----------------|
| <i>P. t. ellioti</i> | 0.13 | 6.69 | 2.79 | 0.15 |
| <i>M. leucophaeus</i> | 0.45 | 5.80 | 2.19 | 0.30 |
| <i>C. torquatus</i> | 0.57 | 6.29 | 3.00 | 0.24 |
| <i>P. preussi</i> | N/A | N/A | N/A | N/A |
| <i>A. preussi</i> | 0.12 | 5.78 | 1.82 | 0.43 |
| <i>C. nictitans</i> | 0.01 | 6.72 | 2.52 | 0.16 |
| <i>C. mona</i> | 0.60 | 5.17 | 2.00 | 0.45 |
| <i>C. p. pogonias</i> | 0.00 | 5.69 | 2.38 | 0.27 |
| <i>C. erythrotis</i> | 0.60 | 2.78 | 2.10 | 0.24 |

For distance to the nearest village, the closest distance a recce survey was to a village was 3.9 km with the greatest distance being 28.08 km. The average primate encounter distance to the nearest village was 14.34 km (S.E. = 0.25). There was no significant difference among average species-specific distances (Kruskal-Wallis, $X^2 = 5.873$, df = 7, p-value = 0.55). However, *C. erythrotis* exhibited the largest average distance from a village (Table 2.12).

Table 2.12. The minimum, maximum, and average distance (km) for each primate species encountered (direct and indirect encounters) from the nearest village found in the Ndokbou forest. Data were combined from 2018 and 2019 recce surveys.

| | Minimum Distance | Maximum Distance | Average Distance | Standard Error |
|-----------------------|------------------|------------------|------------------|----------------|
| <i>P. t. ellioti</i> | 10.60 | 20.69 | 13.88 | 0.39 |
| <i>M. leucophaeus</i> | 11.62 | 19.34 | 14.50 | 0.85 |
| <i>C. torquatus</i> | 5.49 | 21.40 | 15.80 | 1.02 |
| <i>P. preussi</i> | N/A | N/A | N/A | N/A |
| <i>A. preussi</i> | 11.21 | 20.30 | 15.03 | 1.00 |
| <i>C. nictitans</i> | 4.64 | 21.39 | 14.54 | 0.48 |
| <i>C. mona</i> | 5.48 | 15.80 | 13.37 | 1.98 |
| <i>C. p. pogonias</i> | 5.04 | 21.39 | 13.98 | 0.88 |
| <i>C. erythrotis</i> | 14.40 | 19.48 | 16.50 | 1.03 |

2.3.5 Primate encounter geographic variables: terrain ruggedness

The VRM index ranges between 0 and 1, with 0 indicating no ruggedness and 1 complete ruggedness. The values I obtained ranged from 3.8×10^{-4} to 1.23×10^{-2} . Overall, the average VRM across all primate encounters was 3.42×10^{-3} (S.E. = 1.8×10^{-4}). There were no significant differences among species in the ruggedness of the terrain where they were found (Kruskal-Wallis, $X^2 = 4.91$, df = 7, p-value = 0.67). *C. p. pogonias* exhibited the lowest ruggedness average and was encountered in the least rugged terrain with the lowest minimum VRM of all species (Table 2.13). *C. mona* had the greatest average ruggedness value and the largest minimum VRM value. While not exhibiting large overall average ruggedness values, *P.t.elliotti* and *C. nictitans* were encountered in regions that exhibited the largest maximum ruggedness values.

Table 2.13. Minimum, maximum, and average Vector Ruggedness Measurement (VRM) values for each primate species encountered in the Ndokou forest. Data were compiled from 2018 and 2019 surveys.

| | Minimum Value | Maximum Value | Average Value | Standard Error |
|-----------------------|-----------------------|------------------------|---|-----------------------|
| <i>P. t. elliotti</i> | 0.38×10^{-4} | 12.33×10^{-3} | 3.24×10^{-3} | 0.29×10^{-4} |
| <i>M. leucophaeus</i> | 0.61×10^{-4} | 10.15×10^{-3} | 3.47×10^{-3} | 0.61×10^{-4} |
| <i>C. torquatus</i> | 0.56×10^{-4} | 10.27×10^{-3} | 3.53×10^{-3} | 0.76×10^{-4} |
| <i>P. preussi</i> | N/A | N/A | N/A | N/A |
| <i>A. preussi</i> | 1.26×10^{-3} | 5.07×10^{-3} | 3.26×10^{-3} | 0.91×10^{-4} |
| <i>C. nictitans</i> | 1.35×10^{-3} | 12.70×10^{-3} | 3.72×10^{-3} | 0.35×10^{-4} |
| <i>C. mona</i> | 2.99×10^{-3} | 10.50×10^{-3} | 4.92×10^{-3} | 1.44×10^{-4} |
| <i>C. p. pogonias</i> | 0.27×10^{-4} | 8.95×10^{-3} | 2.72×10^{-3} | 0.38×10^{-4} |
| <i>C. erythrotis</i> | 1.16×10^{-3} | 11.00×10^{-3} | 4.51×10^{-3} | 1.82×10^{-4} |

When reviewing VRM values with elevation incorporated into the measure, the overall average index is 2.93 (S.E. = 0.20). When comparing the index values across species the differences are not significant (Kruskal-Wallis, $X^2 = 3.43$ df = 7, p-value = 0.84). However, *C. mona* has the lowest average ruggedness value, indicating encounters were at low ruggedness and

low elevation. *C. erythrotis* and *M. leucophaeus* exhibited the greatest average index value (Table 2.14), indicating their encounters were both rugged and at high elevations. *C. nictitans* exhibits the greatest range of index values, showing those encounters ranged from low ruggedness to high ruggedness at different elevations. *P.t. ellioti* and *A. preussi* had some of the largest maximum values, indicating they were encountered at some of the most rugged and high elevation regions of the forest.

Table 2.14. Minimum, maximum, and average Vector Ruggedness Values (VRM) with the incorporation of elevation (m) for each primate species encounter in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys.

| | Minimum Value | Maximum Value | Average Value | Standard Error |
|-----------------------|---------------|---------------|---------------|----------------|
| <i>P. t. ellioti</i> | 0.30 | 14.37 | 2.86 | 0.33 |
| <i>M. leucophaeus</i> | 0.23 | 9.61 | 3.06 | 0.66 |
| <i>C. torquatus</i> | 0.24 | 10.03 | 3.01 | 0.85 |
| <i>P. preussi</i> | N/A | N/A | N/A | N/A |
| <i>A. preussi</i> | 0.30 | 14.47 | 2.83 | 1.14 |
| <i>C. nictitans</i> | 0.15 | 15.07 | 3.21 | 0.40 |
| <i>C. mona</i> | 0.79 | 2.28 | 1.59 | 0.32 |
| <i>C. p. pogonias</i> | 0.19 | 6.05 | 2.00 | 0.34 |
| <i>C. erythrotis</i> | 0.65 | 8.84 | 3.96 | 1.56 |

2.3.6 Primate encounter geographic variables: elevation and slope

The overall average elevation at which primate encounters occurred was 746.46 m (S.E. = 15.63). When reviewing average elevation between species, the differences were not statistically significant at a 0.05 significance level (Kruskal-Wallis, $X^2 = 13.43$, df = 7, p-value = 0.06). *C. erythrotis* exhibited the highest average elevation, however, with large standard error (Table 2.15). *P.t. ellioti* and *M. leucophaeus* had the next highest average elevation, while *C. mona* and *C. p. pogonias* exhibited the lowest average elevation. While most maximum

evaluations were similar among species, *C. mona* exhibited by far the lowest elevation of all other species.

Table 2.15. Minimum, maximum, and average elevation (m) at which primate species were encountered in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys.

| | Minimum Value | Maximum Value | Average Value | Standard Error |
|-----------------------|---------------|---------------|---------------|----------------|
| <i>P. t. ellioti</i> | 230.45 | 1,174.67 | 797.06 | 20.69 |
| <i>M. leucophaeus</i> | 173.40 | 1,218.14 | 775.16 | 62.19 |
| <i>C. torquatus</i> | 185.43 | 1,174.79 | 694.53 | 80.02 |
| <i>P. preussi</i> | N/A | N/A | N/A | N/A |
| <i>A. preussi</i> | 333.67 | 1,224.66 | 729.41 | 85.75 |
| <i>C. nictitans</i> | 171.08 | 1,228.25 | 735.57 | 29.70 |
| <i>C. mona</i> | 216.64 | 730.62 | 370.61 | 92.49 |
| <i>C. p. pogonias</i> | 167.44 | 1,059.30 | 682.48 | 47.56 |
| <i>C. erythrotis</i> | 556.92 | 1,058.20 | 807.52 | 103.92 |

The overall average slope at which primate encounters occurred in the Ndokbou forest was 11.85 degrees (S.E. = 0.32). There was a significant difference when comparing the average slope across species (Kruskal-Wallis, $X^2 = 20.7$, df = 7, $p = 0.004$). *P.t. ellioti* had a significantly greater average slope than *C. torquatus* (Table 2.16). While *C. nictitans* had an equal average slope to *P. t. ellioti*, it exhibited the lowest minimum slope encountered. *A. preussi* had the largest minimum slope of all of the primate species.

Table 2.16. Minimum, maximum, and average slope (degrees) at which primate species were encountered in the Ndokbou forest. Data were compiled from 2018 and 2019 surveys.

| | <i>P. t. ellioti</i> | <i>M. leucophaeus</i> | <i>C. torquatus</i> | <i>P. preussi</i> | <i>A. preussi</i> | <i>C. nictitans</i> | <i>C. mona</i> | <i>C. p. pogonias</i> | <i>C. erythrotis</i> |
|----------------|----------------------|-----------------------|---------------------|-------------------|-------------------|---------------------|----------------|-----------------------|----------------------|
| Min. value | 1.82 | 2.98 | 2.98 | N/A | 6.35 | 1.13 | 3.37 | 3.17 | 2.26 |
| Max. value | 22.69 | 19.85 | 16.79 | N/A | 19.43 | 22.69 | 14.15 | 22.69 | 18.19 |
| Avg. value | 13.22 | 11.68 | 8.02 | N/A | 12.75 | 11.19 | 6.93 | 11.88 | 11.39 |
| Standard error | 0.47 | 1.12 | 1.20 | N/A | 1.34 | 0.60 | 1.89 | 1.04 | 2.93 |

2.3.7 PCA of primate encounter geographic variables

PCA analysis of primate species encounters and geographic variables demonstrated that none of the analyzed geographic variables had a strong influence on *C. mona*, *C. nictitans*, or *C. p. pogonias* encounters (Figure 2.11). Distance to villages and the VE index (VRM and elevation) had the strongest influence on *C. torquatus* and *C. erythrotis*. Slope and distance to roads was most important for *M. leucophaeus* and *P.t. ellioti* encounters. *A. preussi* was somewhat affected by elevation and distance to roads. *P. preussi* was not included in the analysis because of only one encounter with this species.

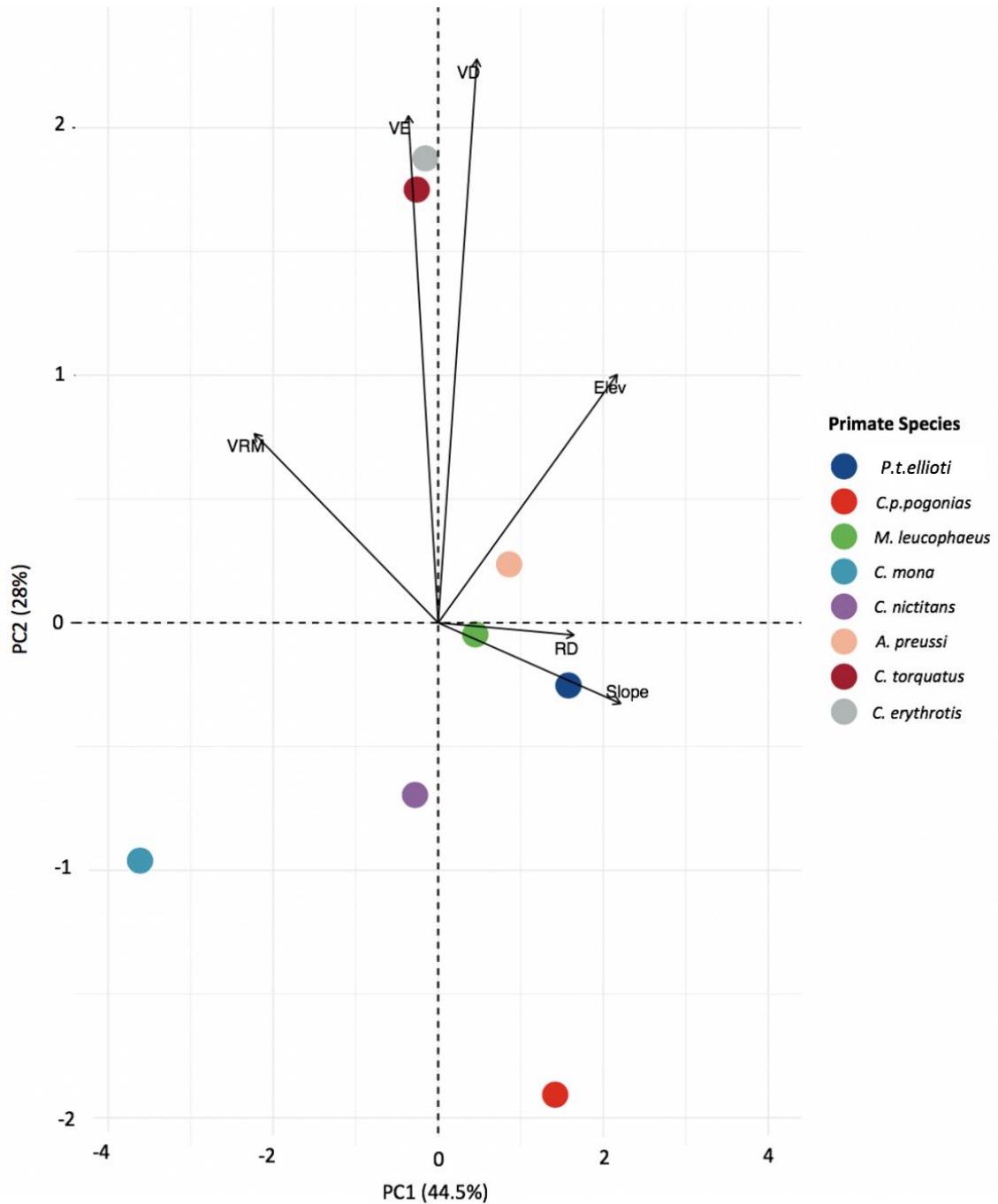


Figure 2.11. Principal component analysis (PCA) on primate species encounters using averages of geographic variables encountered in the Ndokobu forest (variable labels: VRM = Vector Ruggedness Measure, VE = VRM and Elevation index, VD = distance to nearest village, Elev = elevation, RD = distance to nearest road).

2.3.8 Primate relative abundance estimates compared to Makombe and Korup NP forests

I compared primate abundance estimates from the 2018 and 2019 datasets from the Ndokbou forest to those from 2018 surveys of the Makombe forest (Table 2.17). When comparing overall primate encounter frequency, the Ndokbou forest has nearly double the primate abundance that the Makombe forest exhibits. When comparing the overall primate sighting frequency between forests, the Ndokbou and Makombe forests exhibit identical sighting frequency estimates (Table 2.18).

Table 2.17. The overall primate encounter frequency (groups/km) compared between the Ndokbou and Makombe forest.

| | Ndokbou Forest | Makombe Forest |
|------------------------------------|-----------------------|-----------------------|
| Distance surveyed (km) | 421.95 | 174.95 |
| Total no. of encounters | 257 | 78 |
| Overall encounter frequency | 0.61 | 0.45 |
| Standard error | 0.07 | 0.15 |

Table 2.18. The overall primate sighting frequency (groups/km) compared between the Ndokbou and Makombe forests.

| | Ndokbou Forest | Makombe Forest |
|-----------------------------------|-----------------------|-----------------------|
| Distance surveyed (km) | 421.95 | 174.95 |
| Total no. of sightings | 90 | 37 |
| Overall sighting frequency | 0.21 | 0.21 |
| Standard error | 0.04 | 0.11 |

Species-specific comparisons of primate encounter frequency between forests indicate that the Ndokbou forest has greater encounter frequency of nearly every primate species except for *C. mona*. And the two forests have nearly the same encounter frequency of *C. p. pogonias* and *C. erythrotis* (Table 2.19). But the Ndokbou forest exhibits more than double the encounter frequency across almost all Threatened primate species compared to the Makombe forest.

Many individual species exhibit similar sighting frequencies in the two forests (Table 2.20). However, *P.t.elliotti* was not sighted in the Makombe forest and *A. preussi* has more than triple the sighting frequency in the Ndokbou forest. *Cercopithecus* sp. sighting frequencies were mostly similar between the two forests with *C. mona* and *C. p. pogonias* exhibiting slightly larger sighting frequencies in the Makombe forest.

Table 2.19. The overall primate encounter frequency (sightings and vocalization encounters) (groups/km) for each species of primate compared between the Ndokbou and Makombe forests.

| Species | Ndokbou Forest | Makombe Forest |
|--------------------------------|-----------------------|-----------------------|
| <i>P. troglodytes elliotti</i> | 0.02 | 0.00 |
| <i>M. leucophaeus</i> | 0.05 | 0.02 |
| <i>C. torquatus</i> | 0.05 | 0.01 |
| <i>P. preussi</i> | 0.003 | 0.00 |
| <i>A. preussi</i> | 0.04 | 0.01 |
| <i>C. nictitans</i> | 0.30 | 0.13 |
| <i>C. mona</i> | 0.03 | 0.11 |
| <i>C. pogonias pogonias</i> | 0.11 | 0.12 |
| <i>C. erythrotis</i> | 0.04 | 0.03 |

I also compared the primate sighting frequencies of the Makombe and Ndokbou forests with two regions of Korup National Park (KNP), which have similar diurnal primate communities (Linder, 2008). At the time that Linder (2008) conducted surveys in KNP, southern KNP was more protected from hunting activities with more tourist and research activity than the northeastern region, which is why I make comparisons distinguishing the two KNP regions.

Results indicate that both regions of KNP exhibit greater sighting frequencies for *P. preussi* than the Ndokbou and Makombe forests (Table 2.20). However, the Ndokbou forest has a greater sighting frequency for *P.t. ellioti* than both regions of KNP. Southern KNP has greater *M. leucophaeus* and *C. torquatus* sighting frequencies. Overall, both regions of KNP have double the primate sighting frequencies than the Ndokbou and Makombe forests.

Table 2.20. Primate sighting frequency (groups/km) compared between two regions of Korup National Park (Linder, 2008), and the Ndokbou and Makombe forests.

| Species | Korup NP (Northeast) | Korup NP (South) | Ndokbou Forest | Makombe Forest |
|---------------------------------------|---------------------------------|-----------------------------|---------------------------|---------------------------|
| <i>P. troglodytes ellioti</i> | 0.00 | 0.00 | 0.004 | 0.00 |
| <i>M. leucophaeus</i> | 0.00 | 0.01 | 0.007 | 0.006 |
| <i>C. torquatus</i> | 0.00 | 0.01 | 0.006 | 0.006 |
| <i>P. preussi</i> | 0.05 | 0.05 | 0.00 | 0.00 |
| <i>A. preussi</i> | Not Present | Not Present | 0.02 | 0.006 |
| <i>C. nictitans</i> | 0.22 | 0.15 | 0.09 | 0.06 |
| <i>C. mona</i> | 0.09 | 0.03 | 0.02 | 0.05 |
| <i>C. pogonias pogonias</i> | 0.04 | 0.08 | 0.04 | 0.07 |
| <i>C. erythrotis</i> | 0.05 | 0.10 | 0.02 | 0.02 |
| Overall Sighting Frequency | 0.45 | 0.43 | 0.21 | 0.21 |

2.4 Discussion

2.4.1 Primate species abundance and distribution

Results indicate that overall primate abundance is not significantly different across locations of the Ndokbou forest, contrary to my prediction that regions surrounding Mt. Sinai would exhibit the largest primate abundance. However, there are notable differences in the composition of primate species encounters. Guenons, specifically *C. nictitans* and *C. p. pogonias* were the most sighted and overall most encountered primate species in the Ndokbou forest. While *P. t. ellioti*, *M. leucophaeus*, *C. torquatus*, and *P. preussi* were the least sighted and among the least encountered primate species. These results resemble findings from primate surveys conducted in 2008 in Korup National Park (KNP) where *C. nictitans* was one of the most frequently encountered primate species and *M. leucophaeus* and *C. torquatus* were least frequently sighted across all survey locations (Linder, 2008).

Overall, *C. nictitans* were the most widespread primate species encountered in the Ndokbou forest. *C. nictitans* sightings occurred in 6 out of 7 of the 2019 survey grids with vocalization encounters in every grid. *C. p. pogonias* was also extremely widespread with encounters in every survey grid. Similarly, Dowsett-Lemaire & Dowsett (2001) found that *C. nictitans* was the most widespread primate species in the Ndokbou forest but indicated *C. mona* was the next most widespread species, with populations found in secondary vegetation close to Ndokmen Nord where people reportedly did not shoot them at the time. However, my results found *C. mona* to be the least frequently encountered *Cercopithecus* species with the largest encounter frequency occurring east of the Grand Nouya river in grid 26.

There were no direct sightings of *P. preussi*, with only one indirect vocalization occurring during surveys. The single vocalization event occurred in grid 19 of the Mt. Sinai region of the forest, which is furthest from both villages and main roads. Two additional vocalization events occurred outside of surveys from the base camp of grid 19. One occurred to the north of camp at approximately 06:00 the morning of the survey where the official

vocalization was encountered in grid 19. Then another vocalization was heard from camp that evening at approximately 18:15 to the south of camp. However, subsequent surveys in this grid did not provide any further encounters with *P. preussi*. These vocalization events support reports from Dowsett-Lemaire & Dowsett (2001) indicating the presence of *P. preussi* in the hills of Mt. Sinai.

I encountered no sightings of *P. t. elliotti* or *C. torquatus* in any grid during 2019 surveys. However, I had direct sightings of *A. preussi* in 5 out of 7 grids and indirect encounters in 6 out of 7 of the survey grids. These findings support reports from Dowsett-Lemaire & Dowsett (2001) indicating locally common populations of *A. preussi* in the Ndokbou forest. However, they also noted vocalizations directly near the village of Ndokmen Nord in secondary forests. In contrast, my results indicate *A. preussi* has one of the largest average encounter distances from villages of all primate species with their largest encounter rate occurring in grid 34, which is located farthest from Ndokmen Nord.

M. leucophaeus is one of the least encountered primate species in the Ndokbou forest. Dowsett-Lemaire & Dowsett (2001) indicated “large numbers” of *M. leucophaeus* including some groups of over 30 individuals found in several places near Mt. Sinai in the Ndokbou forest. I did not have any encounters (sightings or indirect) with *M. leucophaeus* in grid 19 where Mt. Sinai is located, however neighboring grid 20 to the east, exhibited the largest encounter frequency of *M. leucophaeus* (0.06 groups/km).

While *P. t. elliotti* indirect encounters were excluded from species encounter comparison analyses, indirect encounters occurred in every survey grid except for grid 34. The overall average nesting group size encountered was 3.62 nests (S.E. = 1.18). This is similar to findings from Abwe (2018) who estimated the largest average nesting group size across different survey regions in the Ebo forest was 3.8 nests. However, grids 3 and 10 located closest to villages had larger average nesting group sizes than those closest to Mt. Sinai. Grid 3 also had the only encounter with a ground nest. *G. gorilla* are known to more commonly make ground nests than

arboreal nests with Tutin & Fernandez (1984) distinguishing *P. troglodytes* and *G. gorilla* nests based on the presence of a ground nest with arboreal nests. However, the close proximity of this encounter to the village of Ndokmen Nord with no previous confirmed sightings of *G. gorilla* in the Ndokbou forest, led me to assume this ground nest encounter was *P. t. ellioti*. However, during travel and not during any official survey, there were also three separate nest encounters that only included ground nests in grids 26, 10, and an area east of grid 19. I recorded the number of ground nests of each encounter, their approximate age, and also picture evidence. But ultimately, I did not investigate any further as to if these were *P. t. ellioti* or *G. gorilla*, as this was not a focus of this particular study.

A notable nest encounter occurred in grid 10 where a group of 46 nests all estimated at approximately 1 week old and each within 2-5 m of the nearest nest were encountered. Some studies suggest that clustered *P. troglodytes* nesting in larger groups may be a result of nest site suitability and an antipredation strategy (Ogawa et al. 2007; Last & Muh, 2013). However, *P. t. ellioti* populations found in the Ndokbou forest do not have non-human predators and Abwe (2018) noted that nesting selection in the Ebo forest may be linked to topography or other geographic factors related to safety or comfort, especially in regard to human gun hunting activity at night. Considering grid 10 is one of the nearest grids to Ndokmen Nord, nest site suitability related to antipredation strategies from hunters may explain greater nesting group sizes and an encounter of such a large group of *P. t. ellioti* nests found in grid 10.

Geographic characteristics indicate no significant difference between primate species average distance to villages or roads or topography variables (ruggedness and slope). However, *P. t. ellioti* were encountered on significantly greater slopes than other species. While average comparisons proved no significant differences between primate species, the PCA analysis incorporating all geographic variables did reveal that many guenon species' encounters did not show any particular influence by any geographic parameter. In contrast, *A. preussi*, *P. t. ellioti*, *M. leucophaeus*, and *C. torquatus* encounters were heavily influenced by topography (slope,

elevation, or ruggedness). This supports findings that *A. preussi* are most abundant in forests at high elevations above 800 m and are rarely found in lowland secondary forests (Oates, 2011; Butynski, 2013). This also supports Astaras (2009) who indicated that *M. leucophaeus* prefer higher, more difficult terrain especially to avoid hunting pressures. Overall, *Cercopithecus* primate species were found in a variety of elevations and regions located near and far from human habitation and activity.

2.4.2 Primate abundance comparison between Ndokbou-Makombe forests and Korup NP

My results support my prediction that primate abundance in the Ndokbou and Makombe forests would be less than that of Korup National Park (KNP). Both regions of KNP had more than double the overall primate sighting frequency than the Ndokbou and Makombe forests. Greater sighting frequencies in KNP were also found for almost every primate species compared to the Ndokbou-Makombe forests. *P. t. ellioti* was the only species with a greater sighting frequency in the Ndokbou forest than in either region of KNP. And Makombe had a slightly greater sighting frequency of some of the guenon species than regions of KNP. These results indicate that KNP, an official protected region of Cameroon is exhibiting greater primate abundance than the unprotected regions of Ndokbou and Makombe.

Chapter 3: Hunting and logging activity assessments

3.1 Introduction

The tropical regions of West and Central Africa exhibit some of the highest and most unsustainable rates of bushmeat harvesting in the world (Nasi et al. 2011; Ingram et al. 2015; Dobson et al. 2019). Hunting for bushmeat has shifted as an activity based on subsistence and a source of protein in rural areas to an important source of income for the rural poor with increasing urban consumer demand (Nasi et al. 2011). With bushmeat offtake estimated at 4.5 million tons in the Congo Basin alone (Nasi et al. 2011; Dobson et al. 2019) and 12,000 tons of bushmeat extracted from the Cross-Sanaga region of the Gulf of Guinea (Fa and Brown, 2009), hunting is a major threat to wildlife in this region.

Within the Ebo forest region, primates were found to comprise one of the largest bushmeat biomass offtakes being only second to that of ungulates (Fuashi et al. 2019). Over the course of 16 weeks total, primates were found to comprise 22% of the total hunting offtake and 28% of the total number of animals hunted from the Ebo forest (Fuashi et al. 2019). While there is no available hunting offtake data available for the Ndokbou or Makombe forests, previous studies identify over-hunting in this region, particularly in regards to primates (Dowsett-Lemaire & Dowsett, 2001; Morgan et al. 2011).

In addition, hunting activities can be bolstered in regions where extractive industries such as logging operate (Williamson et al. 2013). Selective logging operations in Central Africa occupy 30-45% of tropical forests and in some countries up to 70% of forests (Poulsen et al. 2009). Logging activities often occur in remote forests, thereby increasing accessibility by creating road networks to previously hard-to-reach forest regions (Laurance et al. 2017). In addition, due to the remoteness of logging operations, companies often fail to provide adequate sources of protein to their workers who turn to bushmeat (Poulsen et al. 2009). One study found that logging operations in the northern Republic of Congo increased the bushmeat supply by 64%

(Poulsen et al. 2009). Ultimately, logging activities can compound threats to wildlife by degrading and fragmenting habitats while facilitating increased levels of hunting.

Mahmoud *et al.* (2019) evaluated land-cover change in Cameroon's Littoral Region, which encompasses the Ebo-Makombe-Ndokbou forest block and found that between 1975 and 2017 natural forests decreased by 420,000 ha with logging and land clearing increasing by 34,838 ha. With the Ndokbou and parts of the eastern Makombe forest under active logging concessions between 2004 and 2017, it is important to also understand the extent and degree to which these forests are being affected by logging concessions.

Apart from the Fuashi *et al.* (2019) study on bushmeat harvesting in the nearby Ebo forest in 2019, there is no current data or research evaluating hunting and/or logging activities within the Ndokbou forest. While the eastern portion of the Makombe forest is a part of FMU 00-004, almost the entirety of the Ndokbou forest is under allocated logging concession 1029 (FMU 00-004). Considering the populations of Threatened primate species found in the Ndokbou forest, it's vital to understand the hunting and logging pressures occurring in this forest in order to evaluate impacts on threatened primate species to develop effective conservation interventions aimed at reducing human threats.

One method of procuring information on hunting patterns is by conducting traditional forest surveys. In some protected regions, park rangers patrol and monitor forests to not only catch illegal hunters but also record signs of hunting (e.g., spent shotgun shells, gunshots, hunting camps) and other human activities. Within the Cross-Sanaga region, national parks including Cross River National Park (CRNP), Nigeria and Korup National Park (KNP), Cameroon utilize traditional forest survey methods by park rangers to assess and deter illegal hunting activities (Astaras et al. 2017; Abanyam, 2018).

However, issues with forest survey methods often arise due to lack of funding and innate data collection biases. Without adequate resources, rangers don't receive proper equipment or training for data collection and interpretation, or there is not enough funding for routine, regular

patrols (Plumptre et al. 2014; Moore et al. 2018). In addition, hunters can collect hunting evidence like shotgun shells or hunt during times when rangers are not patrolling or in regions not regularly patrolled. Therefore, traditional forest survey methods that rely on indirect hunting signs as evidence may only be representing a small portion of the actual amount of hunting occurring (Plumptre et al. 2014; Astaras et al. 2017; Wrege et al. 2017).

Passive acoustic monitoring (PAM) has been recently introduced in African forests as a novel, unbiased method for assessing spatiotemporal gun hunting activities (Astaras et al. 2017; Wrege et al. 2017). Traditionally used to monitor wildlife activity, PAM is increasingly utilized as a conservation tool to assess human activity, such as gun hunting, and its influence on wildlife populations. Acoustic sensors are hung in trees and have the capacity to record sounds 24 hrs/day, 365 days/year. In a tropical forest, depending on the terrain and type of gun used, acoustic sensors can detect gunshots from a distance of approximately 1.5 km (P. Wrege pers. comm.), although this can vary based on topography and other environmental factors. PAM reduces interpretation bias and has proven to provide a more accurate estimate of gun hunting patterns than traditional forest patrols (Astaras et al. 2017).

Passive acoustic monitoring of wildlife and gun hunting has effectively been used in the Republic of Congo, Gabon, and Cameroon (Korup National Park, Rumpi Hills Forest Reserve). In KNP, PAM methods detected a 12% increase in hunting between survey years while traditional techniques for estimating hunting activity failed to detect the change (Astaras et al. 2017). In addition, Astaras *et al.* (2017) estimated that the daily cost of implementing PAM was 23% less expensive than the cost of paying for forest patrol expeditions, reducing annual park costs by 80%.

Bushmeat hunting, especially with shotguns, is widespread in the Ebo-Makombe-Ndokbou forest (Morgan et al. 2013; Dowsett-Lemaire & Dowsett, 2001), home to ten diurnal primate species, eight of which are listed as Threatened by the IUCN Red List of Threatened Species (IUCN, 2020). There are only two previous studies providing bushmeat offtake and

hunting encounter data from the Ebo forest (Morgan et al. 2013; Fuashi et al. 2019) and no direct gun hunting pressure estimates are available for the Ndokbou forest.

I conducted traditional recce surveys in parts of the Ndokbou forest and deployed acoustic sensors to address the following research questions:

1. How does hunting activity vary among different areas of the Ndokbou forest?

Predictions:

- a. Hunting sign encounter rates will increase as distances from roads and villages decrease
- b. Hunting sign encounter rates will increase as terrain ruggedness decreases
- c. Hunting sign encounter rates will increase as elevation decreases
- d. Hunting sign encounter rates will increase as slope decreases

2. How do estimates of hunting pressure vary between hunting sign encounter rates calculated from traditional forest surveys and gunshot frequency calculated from passive acoustic monitoring?

Prediction:

Acoustic sensors will estimate greater gun hunting pressures than forest survey gun hunting estimates

3. How does gun hunting activity vary temporally?

Predictions:

- a. Greater levels of gun hunting will occur during night hours than day hours
- b. Greater levels of gun hunting will occur during the weekdays than on the weekends
- c. Greater levels of gun hunting will occur during months of the dry season (November - December) than months of the wet season (September - November)

4. How do estimates of gun hunting activity in the Ndokbou forest compare to those of the Makombe forest and Korup National Park

Prediction:

The Ndokbou and Makombe forests will exhibit greater levels of gun hunting than the protect Korup National Park

5. How does logging activity and intensity vary across the Ndokbou forest?

Prediction:

Logging sign encounter rates will be greatest in regions closest to villages and roads

With no previous research data available for hunting and logging assessments in the Ndokbou forest, this is the first study to estimate the distribution and encounter rate of hunting and logging pressures in this region. Predictions of hunting activity are based on forest access in regards to human habitation and terrain variables. Forest regions located closest to villages and roads provide the easiest access for hunters into the forest. And in contrast, the most rugged regions of the forest with the largest slopes and elevations such as the Mt. Sinai region of the forest would be the most difficult for hunters to traverse and access for hunting activities.

Acoustic gun hunting predictions, both the comparison to forest survey methods and gun hunting temporal predictions are based on previous acoustic gun hunting pattern findings obtained from Korup National Park (Astaras et al. 2017). I also predicted that compared to Korup National Park where hunting is illegal and ranger patrols take place to deter hunting activities (Astaras et al. 2017), the overall encounter rate of hunting in the Ndokbou forest, where hunting is not restricted or monitored, would be greater. The logging activity prediction was based on easiest road access into the forest, where there is a primary logging road most recently active in 2017 and the main public road located nearest to villages, where I predicted logging activity would be greatest.

3.2 Methods

3.2.1 Forest survey data collection and analysis: hunting activity

I opportunistically collected signs of hunting during forest recce surveys of primates as described in chapter two. During recce surveys, I recorded any signs of hunting which included expended shotgun shell cartridges, wire snare traps, gunshot sounds, camps, trails, and pit-fall traps. I also recorded other miscellaneous signs of human activity including boot prints, tree markings, and trash (i.e. tin cans, batteries, etc.).

Upon encountering a hunting sign I recorded and marked the GPS location and the type of sign. For shotgun shells I estimated the age based on the condition of the shell casing, and for snare traps I noted whether or not the trap was actively set. For camps and trails I noted whether they appeared to be in active use or not. Some hunting signs including shotgun shells and snare traps occurred with more than one sign in the same immediate vicinity (i.e. three snare traps 1 meter apart or two shotgun shells next to each other). When this occurred, I counted each sign as an individual hunting sign encounter.

I calculated hunting sign encounter rates (number of signs/km surveyed) for each recce survey and then pooled recce surveys to obtain averages for each 2019 grid surveyed. I also estimated average encounter rates for each type of hunting sign. Hunting sign encounter rates were compared among grids and among hunting sign types with the non-parametric Kruskal-Wallis test using a significance level of 0.05. However, hunting trails were not included in comparisons of hunting sign encounter rates due to difficulties in assessing if trail encounters were in fact, two different trails or the continuation of one single trail. Hunting encounter rates by type of hunting sign were also analyzed using a PCA to evaluate the importance of each hunting sign type to hunting abundance for each survey grid. Lastly, I combined 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 hunting sign encounters to estimate an overall average hunting sign encounter rate across the Ndokbou forest. I then

compared this overall average with the Makombe forest and Korup National Park (Linder & Oates, 2011) hunting encounter rates.

In addition to hunting encounter rates, I collected and analyzed the same geographic variables I reviewed for primate encounter points discussed in chapter 2 in order to assess any relationship between geographic factors (e.g. terrain ruggedness, slope, distance to roads and villages) and hunting sign encounters. Moreover, for each hunting encounter and using the same methods described in chapter 2, I estimated elevation, slope, distance to nearest village and road (main public road and logging road), VRM index, and VRM with elevation index. I then analyzed these variables using PCA to review the importance of each variable on hunting encounters.

3.2.2 Passive acoustic monitoring: acoustic sensor configuration

I deployed a grid of six “SWIFT” (Cornell University, Ithaca, NY, USA) autonomous acoustic recording units (hereafter, acoustic sensors) in various regions of the Ndokou forest (Figure 3.1). I configured each sensor to record 24 hours a day, 7 days a week at a sampling rate of 8 kHz and a maximum analog gain of 47.5 dB. A sampling rate of 8 kHz allows for recordings of sounds with frequencies up to 4 kHz. Most primate vocalizations do not reach above 2 kHz however, Preuss’s red colobus vocalizations can reach a highest frequency of a little more than 3 kHz (P. Wrege pers. comm.). Gunshot sounds occur between 1 to 2 kHz. I set the analog gain to the maximum of 47.5 dB in order to record sounds at the furthest distance possible. Gunshots could be detected and recorded within ~ 1.5 km-radius, yielding ~ 7.07 km² of detection area per sensor. I set the recording file size to 1500 MB which translated to each sound file containing 24 hours of sound recordings.

Each acoustic sensor was powered using two battery packs that each held 6 D-cell batteries, for a total of 12 D-cell batteries per sensor. Six D-cell batteries can power each sensor for approximately 6 weeks, so with the use of 12 total batteries, each sensor had a maximum run time of 12 weeks. Each sensor recorded and stored sounds onto a 128 GB SD card. With the

configuration settings described above, a 128 GB SD card could store approximately 92 days of sound recordings.

3.2.3 Passive acoustic monitoring: acoustic sensor deployment

I suspended each acoustic sensor approximately 7-10 m above the ground onto a tree branch using tree climbing equipment. Four of the six PAM sensors remained in the same location for the entire duration of data collection, while sensors #3 and #5 had to be moved due to unintentional overlap in the gunshot detection radius with neighboring sensors. Hereinafter “3.1”, “3.2”, “5.1”, and “5.2” refers to location one and location two of sensors 3 and 5, respectively. After sensor 5 and 3 were re-located, each sensor was deployed a minimum of 4 km from the next nearest sensor. I deployed the first sensor on September 26, 2019 with all sensors deployed by September 30, 2019. Once the sensors were deployed, I conducted one routine check to change batteries and swap the original SD cards for a new empty 128 GB SD card for each PAM. I retrieved sensors beginning December 22, 2019 with the final sensor collected on December 27, 2019. Table 3.1 lists the deployment date, retrieval date, total recording effort (days), and total recording area (km²) based on the 1.5 km gunshot detection radius for each acoustic sensor. Sensors 3.1 and 5.1 total detection area was adjusted for overlapping detection areas with nearby sensors (Figure 3.2).

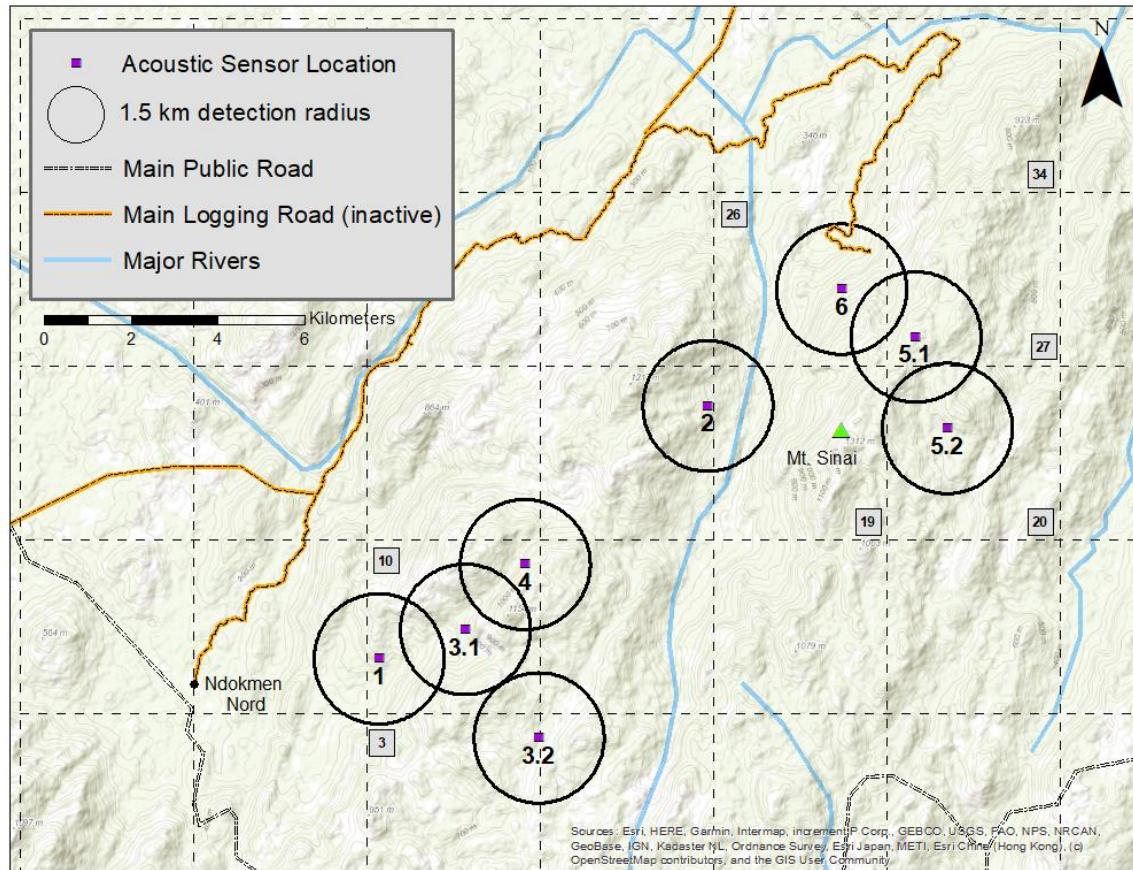


Figure 3.1. The locations of six acoustic sensors used for acoustic data collection in the Ndokbou forest with reference to 1.5 km detection radius. ARUs 3 and 5 have two different deployment locations indicated as “3.1”, “3.2” and “5.1”, 5.2”.

Table 3.1. The deployment date, retrieval date, total recording time (days), and total recording area (km²) for each passive acoustic monitoring sensor deployed in the Ndokou forest. Total recording area is based on the 1.5 km gunshot detection radius for each sensor with the overall total recording area estimate calculated by subtracting overlapping areas between sensors.

| Sensor # | Deployment Date | Retrieval Date | Total Recording Time (days) | Total Recording Area (km ²) |
|-----------------------|-----------------|----------------|-----------------------------|---|
| 1 | Sept. 26, 2019 | Dec. 22, 2019 | 86.91 | 7.07 |
| 2 | Oct. 1, 2019 | Dec. 25, 2019 | 85.01 | 7.07 |
| 3.1 | Sept. 27, 2019 | Nov. 12, 2019 | 46.21 | 7.074.26 |
| 3.2 | Nov. 13, 2019 | Dec. 23, 2019 | 29.87 | 7.07 |
| 4 | Sept. 27, 2019 | Dec. 24, 2019 | 87.93 | 7.07 |
| 5.1 | Sept. 30, 2019 | Nov. 17, 2019 | 47.99 | 7.074.54 |
| 5.2 | Nov. 23, 2019 | Dec. 27, 2019 | 34.04 | 7.07 |
| 6 | Sept. 30, 2019 | Dec. 26, 2019 | 86.92 | 7.07 |
| Overall Total: | | | 514.87 | 51.22 |

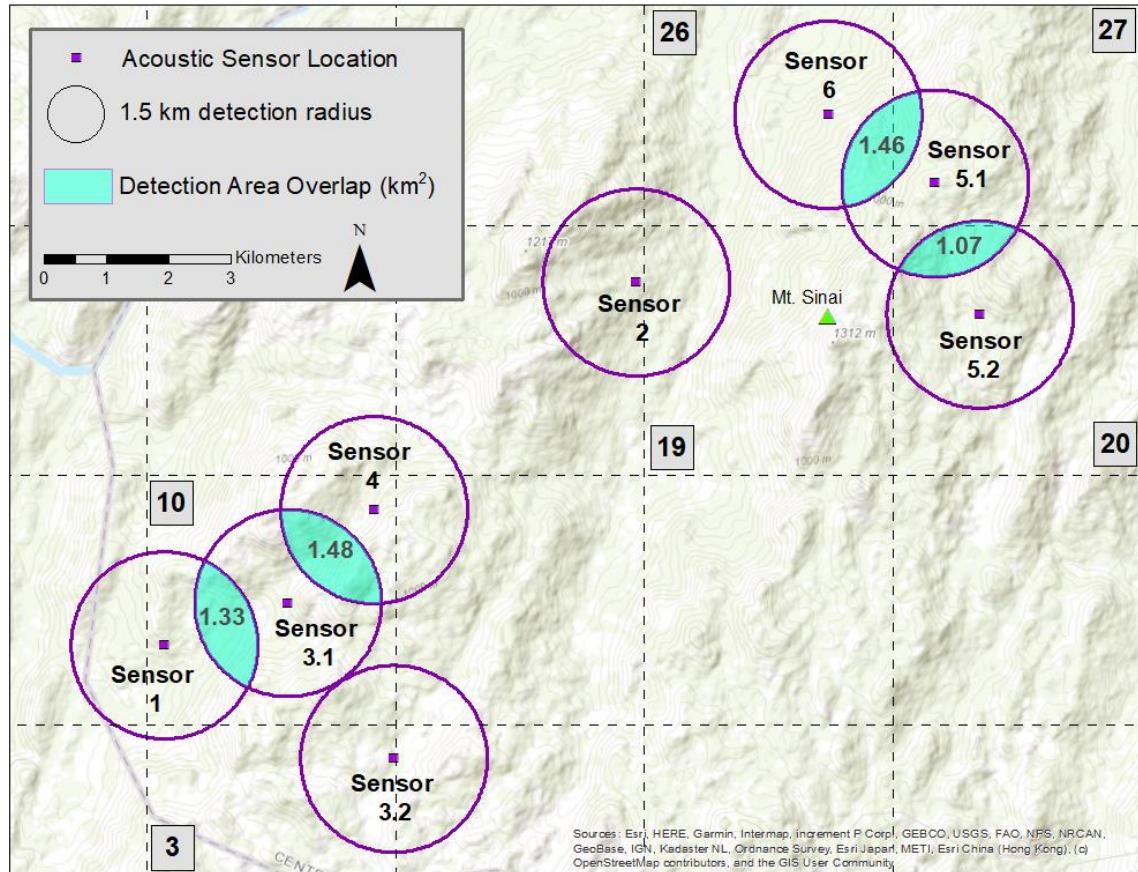


Figure 3.2. Acoustic sensor locations with reference to overlapping detection areas with sensor 3.1 and 5.1 detection areas (numbers in overlap area represent total area km² of overlap).

3.2.4 Passive acoustic monitoring data analysis: gunshot selection review

I analyzed sound recordings collected from acoustic sensors using RavenPro® Interactive Sound Analysis software v. 2.0. Engineers at Cornell University have developed an algorithm used to detect gunshot events from 12-gauge shotguns automatically in sound data using RavenPro. The presence of gun-hunting activity is identified by locating the sound signatures of 12-gauge shotgun shots in sounds files using the algorithm, thereby “detecting” the sounds of gunshots within sound files. This gunshot detector then produces a .txt file containing information on each purported gunshot detection event. This can then be loaded onto RavenPro, which pairs the .txt file with the sound recording from which it came. Using RavenPro I then manually examined (by looking at the spectrogram and/or listening to the purported gunshot) each putative

gunshot detection in order to verify actual hunting events and eliminate false positive detections (e.g., tree falls). For each true positive gunshot event, I recorded the acoustic sensor number that recorded the gunshot, and the date and time the gunshot took place.

Similarly, an algorithm has been developed to detect automatically the vocalizations of Preuss's red colobus. Using the same methods for gun detections, I ran the red colobus detector through all sound files and manually examined each putative detection to eliminate false positive detections.

3.2.5 Passive acoustic monitoring data analysis: gunshot frequency

I calculated an overall average gunshot frequency by summing the total number of verified detections for all sensors and dividing the sum by the total recording effort across all sensors. This allowed for an average gunshot frequency estimate (gunshots/day) across the entire Ndokbou forest region. Gunshot frequency was also estimated for each sensor and compared between sensors.

Given the average number of gunshots/day/sensor, I then calculated the total number of gunshots per year (avg. gunshots/day/sensor x 6 sensors x 365 days/year) in my acoustic monitoring survey area (51.2 km²). I then estimated gunshots/year/km² by dividing the total number of gunshots per year by the total detection area of combined sensor locations (7.07 km² detection area/sensor x 8 sensor locations). However, due to overlapping detection areas between some sensors (Figure 3.2), I calculated the total overlap area (km²) using ArcMap polygon area measurement tool and subtracted this overlap area from the total detection area for the combined eight sensor locations. Using the total number of gunshots/year/km² I then extrapolated this to the total area of the Ndokbou forest (1,000 km²). This allowed for an estimate of the total number of gunshots/year across the entire area of the Ndokbou forest.

I also compared the average gunshots/day for each sensor to gun hunting estimates derived from signs of hunting collected during recce surveys. On a map of the Ndokbou forest,

each region of the seven 4x4 km survey grids was broken down into ~ 925 x 925 m cells. I calculated the sum of gun hunting signs (only shotgun shells and sounds of gunshots) encountered for each cell and represented the sum of gun hunting signs by a color classification scheme ranging from 0 to 4 gun hunting signs encountered. I then overlaid the map with graduated symbols representing levels of gunshot frequencies calculated for each sensor.

3.2.6 Passive acoustic monitoring data analysis: gunshot temporal frequency

I also verified all true positive gun hunting events for temporal distribution on an hourly, weekly, monthly, and seasonal basis by compiling all gunshot detections across all sensors. I compared the percentage of gunshots that occurred during night hours (18:01-05:59) to the percentage that occurred during daylight hours (06:00-18:00). I also estimated gunshot frequency (gunshots/day) for each day of the week and compared between days (Monday-Sunday). Additionally, I compared gunshot frequency between each week (14 weeks total) by combining the number of gunshots recorded by all sensors for each week and dividing the gunshot total by the overall combined recording effort (# of days) across all sensors for each week. I also compared weekly gunshot frequencies between periods of the rainy season (September - November) and dry season (November - December) of the Ndokbou forest. In addition to using the Kruskal-Wallis test to compare the weekly gunshots frequency, I analyzed the relationship between gunshot frequency and recording weeks using the non-parametric Spearman's correlation test. I conducted monthly comparisons using the same methods as weekly comparisons by compiling monthly gunshot totals and monthly recording efforts across all sensors. I made all gunshot frequency comparisons using the non-parametric Kruskal-Wallis test with a significance level of 0.05.

Additionally, I compared gunshot frequency estimates including hourly, weekly, monthly and the overall gunshot frequency to that of Korup National Park where they have also implemented passive acoustic monitoring to assess hunting pressures.

3.2.7 Forest survey data collection and analysis: logging activity

Similar to hunting sign data collection, I also collected logging signs opportunistically during primate recce surveys. Logging signs included cut stumps, cut logs, camps, loading areas, boundary tree markings, roads, other tree markings from logging inventories, and sounds of logging (i.e., machinery).

When encountering a logging sign I recorded and marked the GPS location and type of sign. For cut stumps and cut logs, I recorded the species of tree and the series of numbers imprinted on the stump by the logging company when possible. When I encountered tree markings from logging inventories, I also recorded the species of tree.

I estimated logging sign encounter rates (number of signs/km surveyed) as logging abundance for each recce survey and pooled recce surveys to obtain averages for each 2019 survey grid. I was not able to combine survey data from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) with my survey data for logging signs because the 2018 surveys did not consistently include logging sign encounters for every survey that was completed. So the overall average logging sign encounter rate for the Ndokbou forest is derived exclusively from my 2019 survey data. I used the non-parametric Kruskal-Wallis test using a significance level of 0.05 to compare logging between grids. I also conducted a PCA to evaluate the importance of types of logging signs on logging abundance for each survey grid.

Finally, I combined all hunting and logging encounters from 2019 surveys to estimate an overall human activity encounter rate for the Ndokbou forest. I then compared encounter rates between survey grids and conducted a PCA to evaluate the effects of hunting and logging sign encounters together on each survey grid.

3.3 Results

3.3.1 Hunting encounter frequency

From combined 2018 and 2019 survey data, a total of 284 hunting signs were encountered over a total survey distance of 421.95 km. The resulting mean hunting encounter frequency across the Ndokbou forest was 0.67 signs/km (S.E. = 0.11). Hunting trails were excluded from hunting sign encounter frequency analyses, however, trails were widespread throughout the Ndokbou forest with a total of 204 trail encounters during 2018 and 2019 surveys. When comparing trail encounter rates between 2019 survey grids, grids 10 and 20 had significantly greater trail encounter rates than grid 34, which by far had the lowest rate of trail encounters than all other grids (Table 3.2). Grid 19, which encompasses Mt. Sinai had the next lowest hunting trail encounter rate after grid 34.

There were no significant differences in hunting encounter rates (excluding trails) among 2019 grids (Kruskal-Wallis, $X^2 = 3.7849$, df=6, p-value = 0.71) (Figure 3.3). However, grid 34 had the lowest hunting encounter rate while grids 19 and 3 had the largest hunting encounter rates (Table 3.3). Grid 34 had the lowest encounter rate of hunting trails and overall hunting signs, this grid had one of the highest encounter rates of shotgun shells and snare traps (Figure 3.4). Grid 19 had one of the largest hunting sign encounter rates, pit-fall traps comprised the largest encounter rate in this grid while snare traps, shotgun shells, and gunshots heard comprised a combined encounter rate of less than 0.05 signs/km - the lowest of any grid. Grids 10 and 3 had the highest encounter rates of snare traps.

Table 3.2. Hunting trail sign encounter rates (signs/km) for each 2019 grid surveyed in the Ndokbou forest.

| | Grid 3 | Grid 10 | Grid 19 | Grid 20 | Grid 26 | Grid 27 | Grid 34 |
|---------------------------------|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of hunting trail encounters | 14 | 32 | 8 | 27 | 18 | 12 | 2 |
| Encounter rate | 0.48 | 0.91 | 0.36 | 0.82 | 0.59 | 0.36 | 0.06 |
| Standard error | 0.05 | 0.17 | 0.14 | 0.17 | 0.13 | 0.08 | 0.03 |

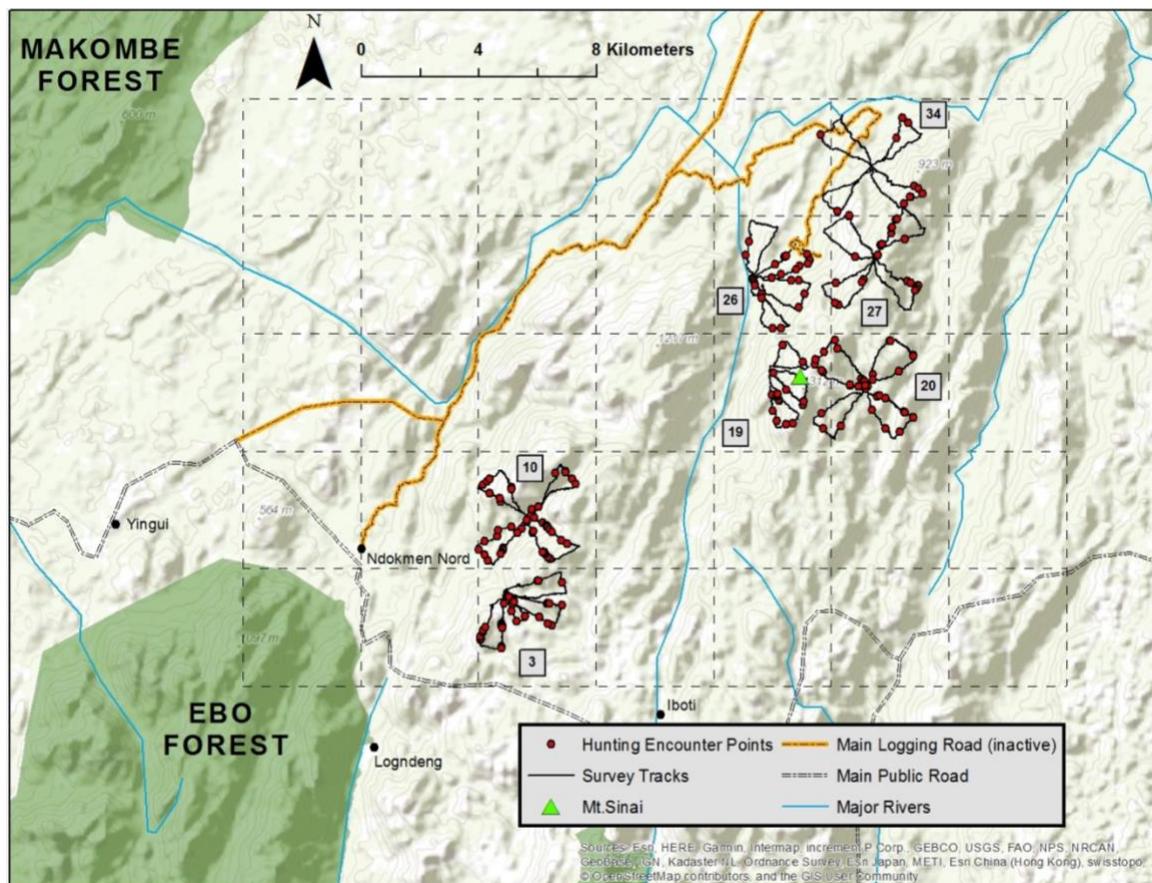


Figure 3.3. All hunting signs encountered during 2019 surveys with reference to grid numbers in gray boxes.

Table 3.3. Hunting sign encounter rate (signs/km) for each 2019 grid surveyed in the Ndokbou forest.

| | Grid 3 | Grid 10 | Grid 19 | Grid 20 | Grid 26 | Grid 27 | Grid 34 |
|--------------------------------|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of hunting sign encounters | 22 | 20 | 18 | 16 | 11 | 10 | 9 |
| Encounter rate | 0.75 | 0.57 | 0.80 | 0.49 | 0.36 | 0.30 | 0.25 |
| Standard error | 0.40 | 0.26 | 0.41 | 0.30 | 0.19 | 0.10 | 0.10 |

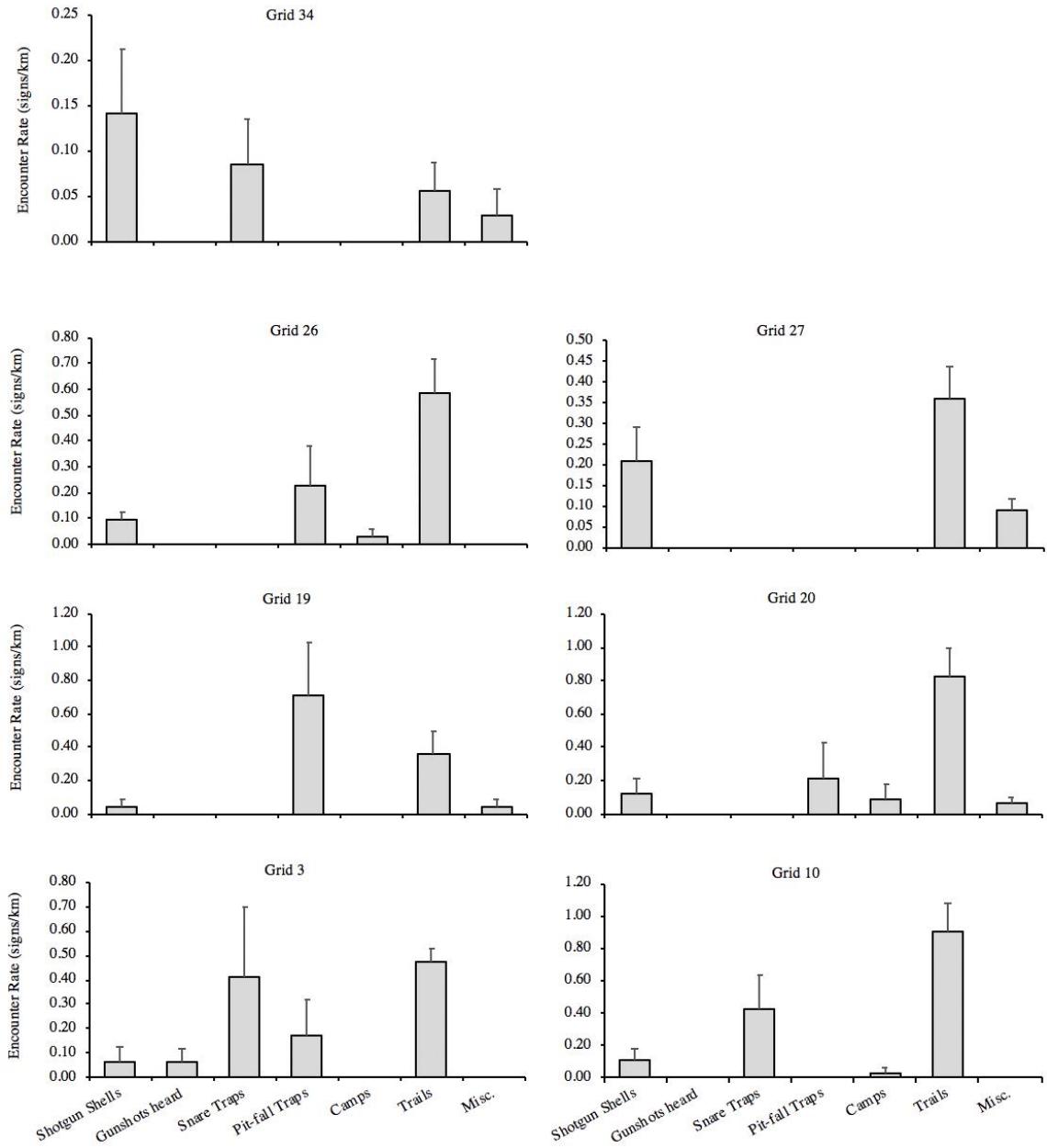


Figure 3.4. Hunting sign encounter rates (signs/km) of each hunting sign type encountered in each 2019 survey grid.

I compared the hunting sign encounter rate, strictly for gun hunting signs (shotgun shells and gunshots heard) among grids. While I found no significant differences among grids (Kruskal-Wallis, $X^2 = 3.24$, df = 6, p = 0.78), grid 19 had the lowest gun hunting sign encounter rate with the next lowest encounter rate being two times greater than that of grid 19 (Table 3.4). Grids 3, 10, 26, and 34 all had similar gun hunting sign encounter rates with grid 27 having the greatest encounter rate of gun hunting signs (Figure 3.5).

Table 3.4. Gun hunting sign (shotgun shells and gunshots heard) encounter rate (signs/km) for each 2019 survey grid.

| | Grid 3 | Grid 10 | Grid 19 | Grid 20 | Grid 26 | Grid 27 | Grid 34 |
|--|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of gun hunting signs | 4 | 4 | 1 | 4 | 3 | 7 | 5 |
| Gun Hunting Sign Encounter rate | 0.14 | 0.11 | 0.04 | 0.12 | 0.10 | 0.21 | 0.14 |
| Standard error | 0.09 | 0.06 | 0.04 | 0.09 | 0.03 | 0.08 | 0.07 |

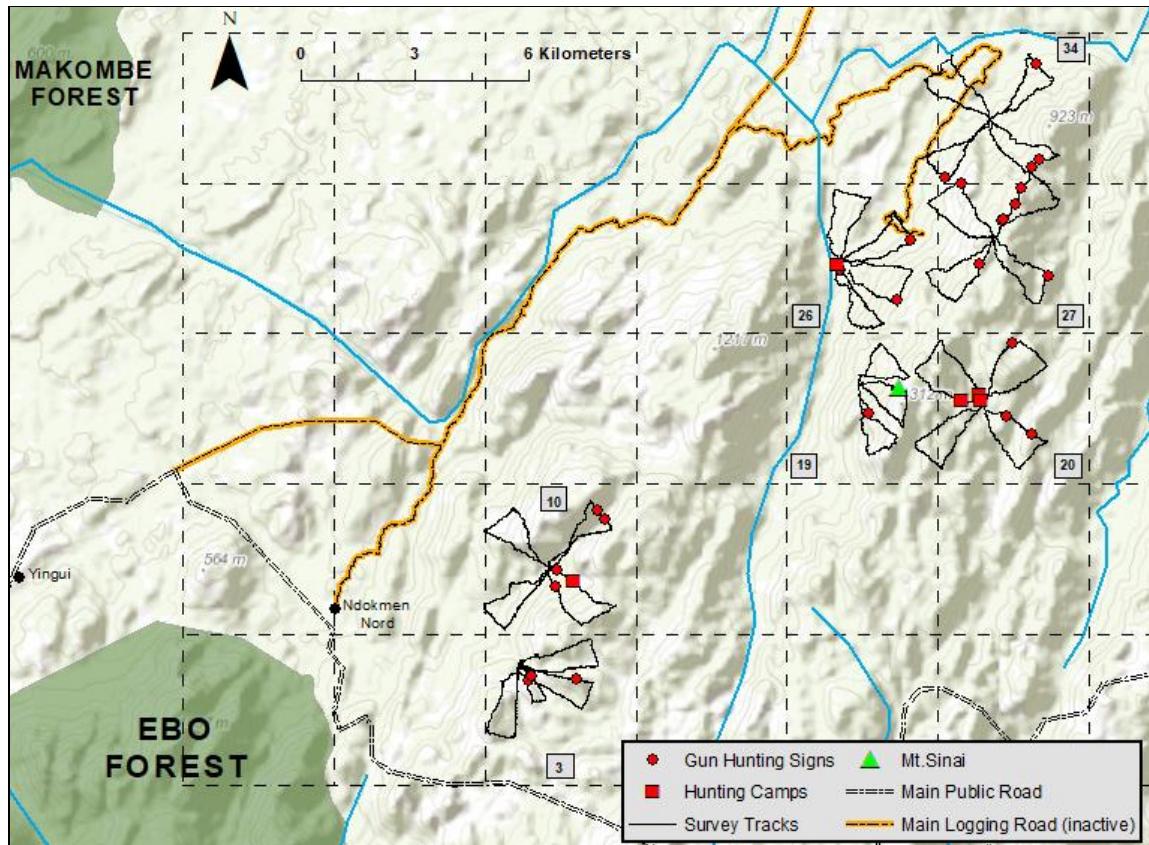


Figure 3.5. Locations of gun hunting signs (shotgun shells and gunshots heard) and hunting camps encountered during 2019 surveys with reference to grid numbers in gray boxes.

When I compared hunting encounter rates among hunting sign types (excluding trails), there was a significant difference between the encounter rates (Kruskal-Wallis, $X^2 = 71.819$, df= 5, $p < 0.001$). Snare traps were encountered most frequently and significantly more than all other signs except for shotgun shells, which had the next highest encounter rate (Table 3.5). Gunshots heard had the lowest encounter rate.

Table 3.5. Combined 2018 and 2019 survey data for hunting sign encounter rates (signs/km) for each type of hunting sign. “Misc.” includes indirect human signs such as boot prints, trash, or tree markings.

| | Shotgun Shells | Gunshots heard | Snare Traps | Pit-fall Traps | Camps | Misc. |
|-----------------------|-----------------------|-----------------------|--------------------|-----------------------|--------------|--------------|
| No. of encounters | 78 | 2 | 143 | 36 | 8 | 17 |
| Encounter rate | 0.17 | 0.006 | 0.30 | 0.09 | 0.02 | 0.04 |
| Standard error | 0.03 | 0.005 | 0.08 | 0.11 | 0.008 | 0.009 |

PCA measures on types of hunting sign in survey grid locations indicated that grids 34, 19, and 27 were not largely affected by any particular hunting sign (Figure 3.6). Grids 3 and 26 were most strongly influenced by gun hunting activity (gunshots heard and shotgun shells respectively). Miscellaneous signs of human activity (i.e. trash, boot prints, etc.) and pit-fall traps were not included in the PCA because they are not directly indicative of hunting. While miscellaneous encounters are signs of human activity, they cannot necessarily be directly linked to hunting activity. In addition, every pit-fall trap encounter was a remnant of the original trap and according to my field guide, had not been in active use in the Ndokbou forest for decades.

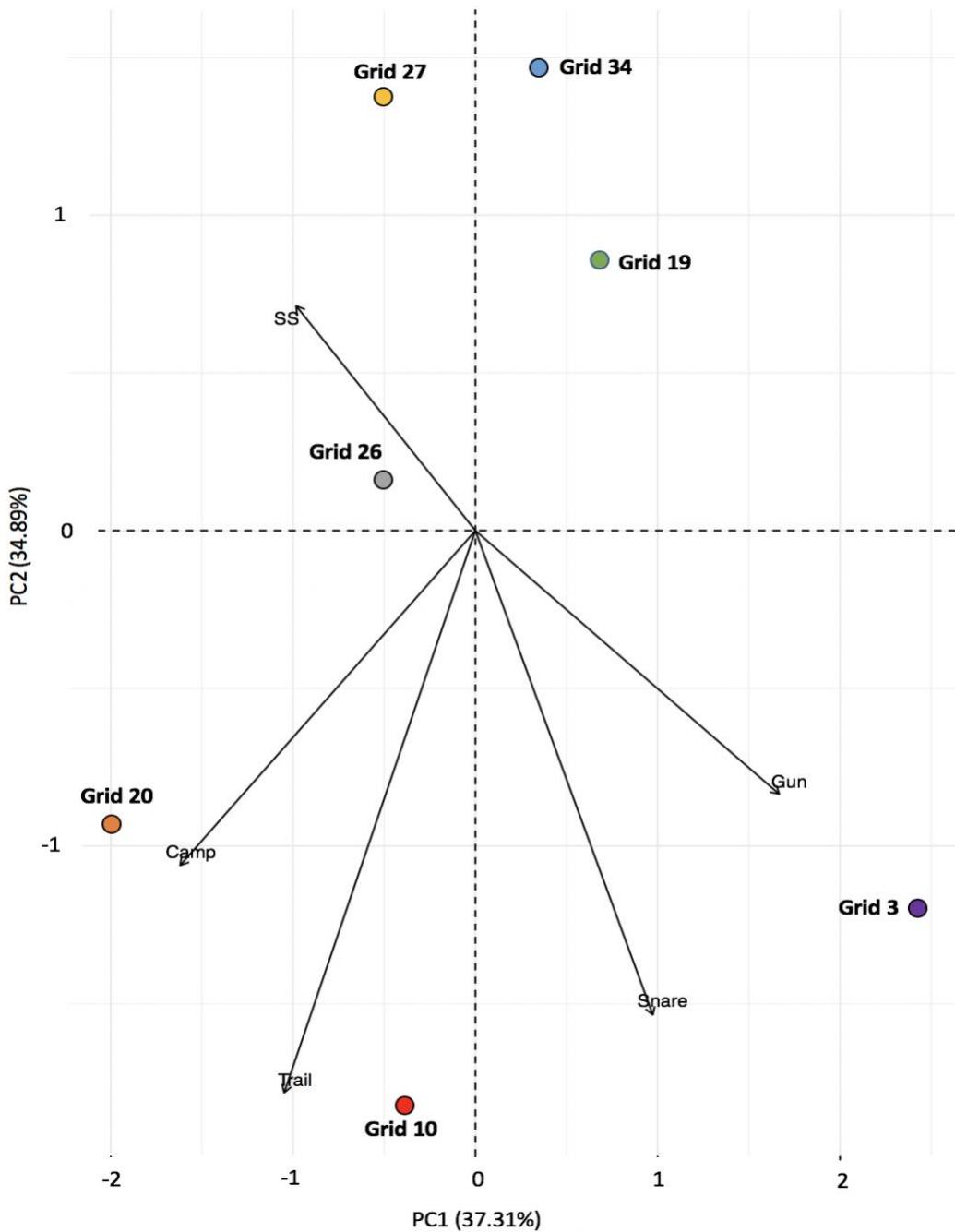


Figure 3.6. Principal component analysis of all hunting signs on survey grids in the Ndokbou forest from 2019 data. Hunting variables: SS = shotgun shells, Gun = gunshots heard, Snare = snare-traps, trail = hunting trails, Camp = hunting camps.

3.3.2 Hunting encounter geographic variables: distance to villages and roads

When I compared hunting sign encounters to the distance of the nearest village, on average hunting activity was occurring 12.78 km (S.E. = 0.27) from villages with the minimum and maximum distances being 3.9 and 28.08 km respectively, based on recce survey locations. When I compared average distance between specific hunting sign types, there was a significant difference between hunting sign type and distance to the nearest village (Kruskal-Wallis, $X^2 = 33.20$, $df = 6$, $p < 0.001$). Shotgun shells were not significantly farther from villages than snare traps (Kruskal-Wallis post-hoc, $p = 0.15$). However, the only significant difference was that miscellaneous signs were found significantly farther than pitfall traps (Kruskal-Wallis post-hoc, $p = 0.03$). But overall, shotgun shells had the largest average distance from villages than any other hunting sign, while gunshots heard had the nearest average distance (Table 3.6). Trails had the largest range of distances compared to all other hunting signs.

The average distance hunting activity was occurring from the main public road was 9.67 km (S.E. = 0.17) with the minimum and maximum possible distance being 1.18 - 16.84 km respectively. When comparing the average distance between types of hunting signs, there was a significant difference (Kruskal-Wallis, $df = 6$, $p < 0.001$). Shotgun shells had the largest average distance and were significantly greater than trails and pitfall traps (Table 3.7). Snare traps also had a significantly greater average than trails and pitfall traps, however they also exhibited the lowest minimum distance to main roads. Trails overall had the largest range of distances from main roads.

Table 3.6 Minimum, maximum, and average distance (km) to the nearest village that each type of hunting sign was encountered in the Ndokbou forest. Data are compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|-------------------|--------------|----------------------|----------------------|--------------|-------------------|---------------------|--------------|
| Min. value | 6.37 | 5.34 | 5.47 | 3.98 | 4.64 | 5.00 | 5.45 |
| Max. value | 17.84 | 20.48 | 21.83 | 21.20 | 20.93 | 16.37 | 21.92 |
| Avg. value | 14.15 | 9.20 | 15.24 | 12.22 | 12.15 | 10.53 | 15.48 |
| Standard error | 1.19 | 3.76 | 0.50 | 0.35 | 0.76 | 0.94 | 1.29 |

Table 3.7. Minimum, maximum, and average distance (km) to the nearest main public road that each type of hunting sign was encountered in the Ndokbou forest. Data is compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|-------------------|--------------|----------------------|----------------------|--------------|-------------------|---------------------|--------------|
| Min. value | 5.62 | 2.87 | 2.76 | 1.23 | 1.22 | 1.63 | 1.97 |
| Max. value | 14.54 | 14.64 | 16.04 | 15.70 | 16.19 | 12.79 | 16.28 |
| Avg. value | 10.29 | 5.90 | 11.25 | 8.74 | 10.41 | 6.69 | 10.50 |
| Standard error | 0.95 | 2.91 | 0.94 | 0.23 | 0.38 | 0.85 | 0.94 |

The overall average distance hunting activity was occurring from the main logging road (inactive) was 2.60 km (S.E. = 0.08) with a possible distance range of 0.00 - 6.78 km. There was a significant difference when comparing the average distance between types of hunting signs (Kruskal Wallis, df = 6, p-value < 0.001). With the second largest average, pitfall traps were found at a greater average distance from logging roads than snare traps and shotgun shells, which were found closest to logging roads (Table 3.8). Trails and shotgun shells were found furthest from logging roads.

Table 3.8. Minimum, maximum, and average distance (km) to the nearest main logging road that each type of hunting sign was encountered in the Ndokbou forest. Data is compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|-------------------|-------------|----------------------|----------------------|--------------|-------------------|---------------------|--------------|
| Min. value | 0.01 | 1.74 | 0.002 | 0.002 | 0.08 | 0.96 | 0.02 |
| Max. value | 4.67 | 6.09 | 6.07 | 6.67 | 5.83 | 6.03 | 5.43 |
| Avg. value | 2.56 | 4.56 | 2.13 | 3.01 | 2.00 | 4.14 | 2.49 |
| Standard error | 0.58 | 0.96 | 0.15 | 0.12 | 0.15 | 0.35 | 0.39 |

3.3.3 Hunting encounter geographic variables: terrain ruggedness

When evaluating the terrain ruggedness of hunting sign encounters using the VRM index, the average ruggedness value across all hunting signs was 3.88 (S.E. = 0.16). Hunting signs significantly differed when comparing average ruggedness values between hunting signs (Kruskal-Wallis, $X^2 = 21.73$, df = 6, p = 0.001). On average, pitfall traps were encountered in regions of the forest with significantly greater ruggedness than those of shotgun shells, trails, snare traps, and miscellaneous hunting signs (Table 3.9). After pitfall traps, gunshots heard were encountered with the next largest average VRM ruggedness value. Trails were encountered in both low and high rugged regions. After miscellaneous signs, snare traps were encountered on average in the least rugged regions compared to other signs.

Using the VE (VRM and elevation) index as a measure of ruggedness, the average value across all hunting signs was 3.10 (S.E. = 0.18). Hunting signs also differed significantly when comparing ruggedness between signs (Kruskal-Wallis, $X^2 = 23.41$, df = 6, p < 0.001). Similar to VRM ruggedness, pitfall traps had the largest average ruggedness value and were encountered in regions significantly more rugged than all other hunting sign types (Table 3.10). However, using VE ruggedness, shotgun shells had the next largest average ruggedness value, and camps were

encountered in the least rugged regions of the forest, exhibiting the smallest average VE ruggedness value.

Table 3.9. Minimum, maximum, and average Vector Ruggedness Measure (VRM) values for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|-------------------|-------------|----------------------|----------------------|--------------|-------------------|---------------------|--------------|
| Min. value | 1.51 | 2.02 | 0.69 | 0.23 | 0.41 | 1.05 | 0.35 |
| Max. value | 6.19 | 8.95 | 11.19 | 12.03 | 11.15 | 12.03 | 10.26 |
| Avg. value | 3.54 | 4.30 | 4.13 | 3.64 | 3.45 | 7.24 | 2.58 |
| Standard error | 0.56 | 1.57 | 0.46 | 0.22 | 0.24 | 0.87 | 0.78 |

Table 3.10 Minimum, maximum, and average VE (VRM and elevation) value for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|-------------------|-------------|----------------------|----------------------|--------------|-------------------|---------------------|--------------|
| Min. value | 0.18 | 1.90 | 0.31 | 0.16 | 0.08 | 0.22 | 0.20 |
| Max. value | 3.44 | 5.41 | 12.14 | 14.05 | 8.14 | 14.58 | 9.87 |
| Avg. value | 1.67 | 3.03 | 3.40 | 3.10 | 2.01 | 6.68 | 2.10 |
| Standard error | 0.34 | 0.80 | 0.45 | 0.25 | 0.21 | 1.14 | 0.78 |

3.3.4 Hunting encounter geographic variables: elevation and slope

The average overall elevation that hunting signs were encountered was 732.19 m (S.E. = 15.35). Hunting signs were encountered at significantly different elevations when comparing average elevation between sign type(Kruskal-Wallis, $X^2 = 31.41$, df = 6, p <0.001). Shotgun shells were found at a significantly higher average elevation than snare traps (Table 3.11). Hunting camps were encountered on average, at the lowest elevations. Pitfall traps were encountered at the highest maximum elevations and trails were encountered at low and high elevations.

The average slope at which hunting signs were encountered was 10.23 degrees (S.E. = 0.29). While there were no significant differences when comparing average slope among types of hunting signs (Kruskal-Wallis, $X^2 = 10.23$, df = 6, p = 0.29), miscellaneous hunting signs occurred at the greatest average slope with hunting camps occurring on the smallest average slopes (Table 3.12). Trails occurred on both large and small slopes, exhibiting the largest maximum slope and one of smallest minimum slopes.

Table 3.11 Minimum, maximum, and average elevation (m) for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|----------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Min. value | 119.90 | 604.30 | 179.60 | 197.70 | 201.90 | 206.10 | 217.70 |
| Max. value | 982.40 | 941.60 | 1,173.30 | 1,215.40 | 1,069.70 | 1,234.60 | 1,000.40 |
| Avg. value | 545.29 | 773.59 | 749.94 | 776.68 | 576.62 | 868.45 | 719.81 |
| Standard error | 119.72 | 68.85 | 34.23 | 19.67 | 35.56 | 78.76 | 69.97 |

Table 3.12 Minimum, maximum, and average slope (degrees) for each type of hunting sign encountered in the Ndokbou forest. Data is compiled from 2018 (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan) and 2019 surveys.

| | Camp | Gunshot Heard | Shotgun Shell | Trail | Snare Trap | Pitfall Trap | Misc. |
|-------------------|-------------|----------------------|----------------------|--------------|-------------------|---------------------|--------------|
| Min. value | 0.49 | 4.79 | 2.26 | 1.87 | 0.76 | 3.37 | 0.76 |
| Max. value | 12.30 | 12.34 | 21.06 | 22.80 | 17.57 | 21.06 | 21.06 |
| Avg. value | 7.17 | 7.65 | 10.84 | 10.42 | 9.88 | 9.47 | 11.46 |
| Standard error | 1.22 | 1.63 | 0.78 | 0.40 | 0.59 | 1.31 | 2.02 |

3.3.5 Hunting encounter rates compared to Makombe and Korup NP forests

I compared hunting encounter rates to those of the Makombe forest from 2018 survey data and Korup National Park (Linder & Oates, 2011). Hunting trails were excluded from all comparison analyses between forests. The northeast region of KNP had the greatest hunting sign encounter rate while the Ndokbou and Makombe forests had the next largest encounter rates. The southern region of Korup NP had the smallest encounter rate exhibiting less than half the hunting encounter rate of the Ndokbou and Makombe forests (Table 3.13).

When I compared the types of hunting signs encountered between the three regions, shotgun shells were encountered most frequently by far in northeast Korup NP and also in southern Korup NP. Snare traps were most frequent in the Makombe and Ndokbou forests (Table 3.14). The least encountered hunting signs in both regions of Korup NP were snare traps and miscellaneous hunting signs.

Table 3.13. The overall hunting encounter rate (signs/km) compared between the Ndokbou, Makombe (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan), and Korup National park (Linder, 2008) forests.

| | Ndokbou Forest | Makombe Forest | Korup NP (Northeast) | Korup NP (South) |
|-------------------------------|-----------------------|-----------------------|-----------------------------|-------------------------|
| Distance surveyed (km) | 421.95 | 149.67 | 96.63 | 293.32 |
| Total no. of encounters | 284 | 105 | 97 | 52 |
| Overall encounter rate | 0.67 | 0.70 | 1.00 | 0.18 |
| Standard error | 0.11 | 0.38 | 0.44 | 0.08 |

Table 3.14. The encounter rate (signs/km) of each type of hunting sign compared between Ndokbou, Makombe (data provided by C. Jost Robinson, J. Linder, E. Abwe, and B. Morgan), and Korup National Park (Linder, 2008) forests. Total number of signs encountered are in parenthesis.

| Hunting Sign | Ndokbou Forest | Makombe Forest | Korup NP (Northeast) | Korup NP (South) |
|---------------------|-----------------------|-----------------------|-----------------------------|-------------------------|
| Shotgun shells | 0.18 (78) | 0.16 (24) | 0.58 (56) | 0.08 (22) |
| Gunshots heard | 0.005 (2) | 0.02 (3) | 0.12 (12) | 0.03 (10) |
| Snare traps | 0.34 (143) | 0.45 (68) | 0.01 (1) | 0.00 (0) |
| Misc. | 0.04 (17) | 0.03 (5) | 0.07 (7) | 0.00 (0) |

3.3.6 Passive acoustic monitoring: gunshot frequency and geographic distribution

The overall total recording effort from the combined six sensors was 12,346.87 hours or 514.87 days and a total of 238 true positive gunshots were detected resulting in an overall average of 0.46 gunshots/day/sensor (S.E. = 0.06). This equates to a rate of 1,007.40 gunshots/year within the 51.22 km² gunshot detection area and ultimately, 19,668.10 gunshots/year across the entire area of the Ndokbou forest (1,000 km²).

When comparing gunshot frequency between sensors (Figure 3.7), there was a significant difference (Kruskal-Wallis, $X^2 = 25.514$, $df = 7$, $p < 0.001$). Overall Sensor 2 exhibited the greatest overall gunshot frequency while sensor 5.2 had the lowest (Table 3.15). The gunshot frequency of Sensor 2 was significantly greater than sensors 4, 5.1, and 5.2.

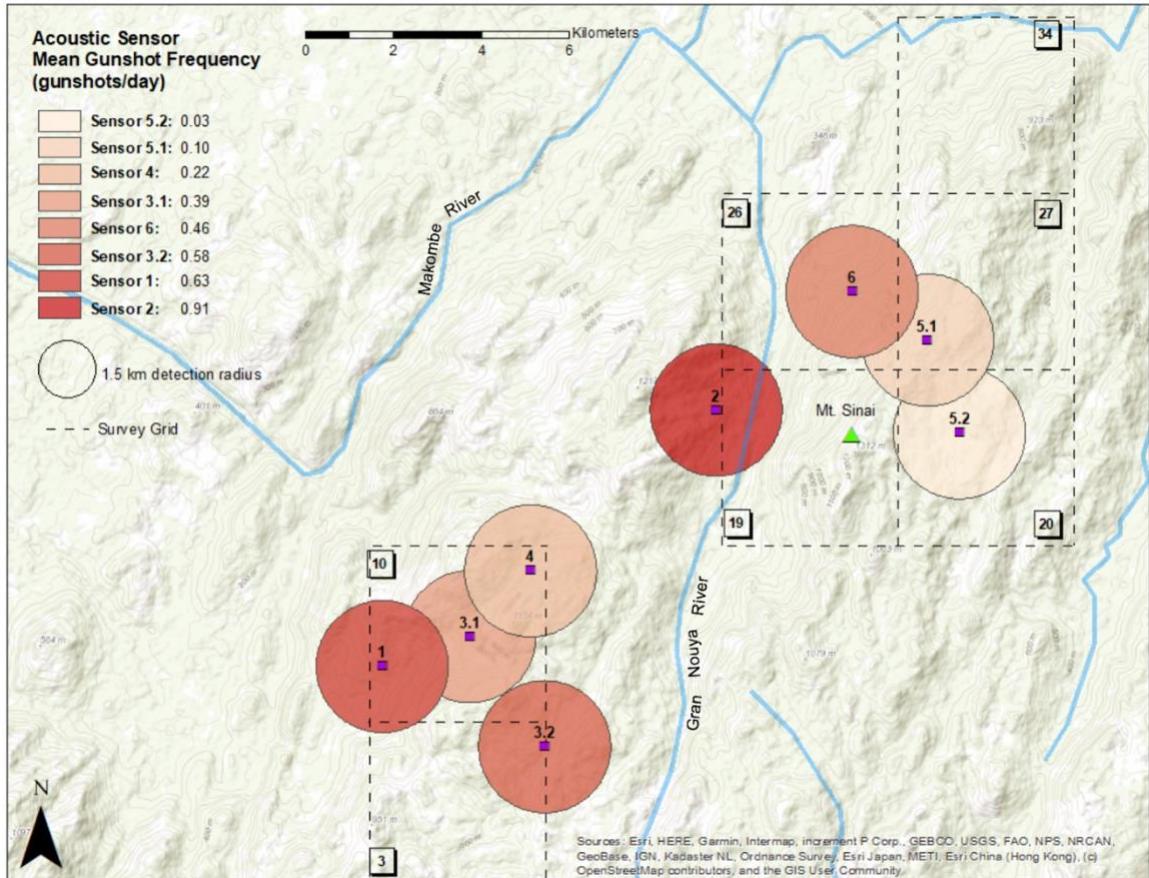


Figure 3.7. Acoustic sensor location and mean gunshot frequency (gunshots/day) with reference to survey grid numbers.

Table 3.15 Gunshot frequency (gunshots/day) detected by each passive acoustic sensor located in the Ndokbou forest.

| | Sensor 1 | Sensor 2 | Sensor 3.1 | Sensor 3.2 | Sensor 4 | Sensor 5.1 | Sensor 5.2 | Sensor 6 |
|-------------------------------|-------------|-------------|---------------|---------------|-------------|---------------|---------------|-------------|
| No. of gunshots | 55 | 77 | 18 | 23 | 19 | 5 | 1 | 40 |
| Total recording effort (days) | 86.91 | 85.01 | 46.21 | 39.87 | 87.93 | 47.99 | 34.04 | 86.92 |
| Gunshot frequency | 0.63 | 0.91 | 0.39 | 0.58 | 0.22 | 0.10 | 0.03 | 0.46 |
| Standard error | 0.18 | 0.24 | 0.19 | 0.22 | 0.09 | 0.06 | 0.03 | 0.15 |

Figure 3.8 presents a geographic comparison of levels of gun hunting pressures as measured by acoustic sensor data and recce survey data. Acoustic sensors indicated the greatest gun hunting pressure was occurring in the region northwest of grid 19 (where no recce gun hunting data are available). But acoustic sensor data also indicated that high gunshot frequencies were occurring in regions where grids 3 and 10 are located, while regions of grids 20 and 27 exhibited the lowest gunshot frequencies. Similarly, recce survey data indicated the regions of grids 26 and 27 exhibited low gun hunting sign encounters. However, apart from one cell of grid 3 containing 4 gun hunting signs, most other regions of grids 3 and 10 contain zero to one sign of gun hunting.

To further review gun hunting pressures compared between acoustic sensors and recce surveys, I compared gun hunting encounter rates of grids 10 and 20 to gunshot frequencies identified by sensors 3.1 and 5.2 located in grids 10 and 20 respectively. Recce survey data indicated that grids 10 and 20 had near identical encounter rates of gun hunting signs with both grids having 4 gun hunting sign encounters (Figure 3.9). While acoustic sensor data showed that the gunshot frequency in grid 10 (sensor 3.1) was nearly four times greater than the gunshot frequency in grid 20 (sensor 5.2) (Figure 3.10).

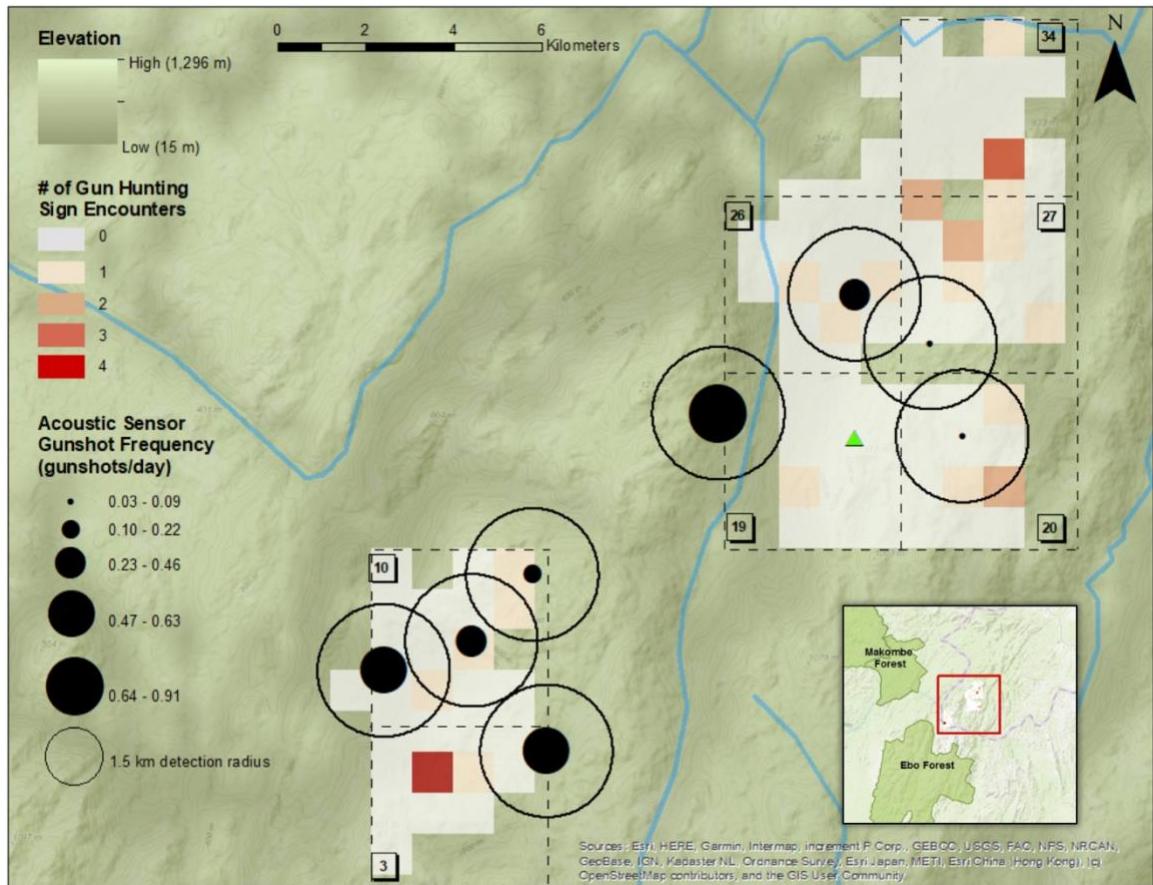


Figure 3.8. The geographic distribution of gun hunting pressures identified by gunshot frequency estimates (mean gunshots/day/sensor) from sound data recorded by acoustic sensors compared to the number of gun hunting signs encountered during recce surveys with reference to survey grid numbers in boxes.

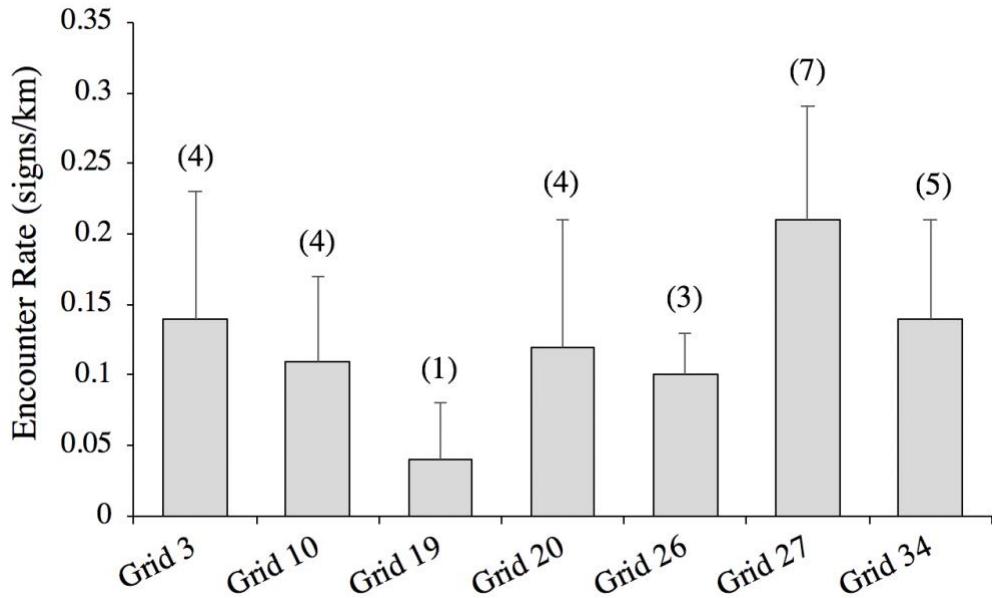


Figure 3.9. Encounter rates of gun hunting signs (signs/km) for each 2019 survey grid. Numbers above bars indicate the total number of gun hunting signs encountered in each grid.

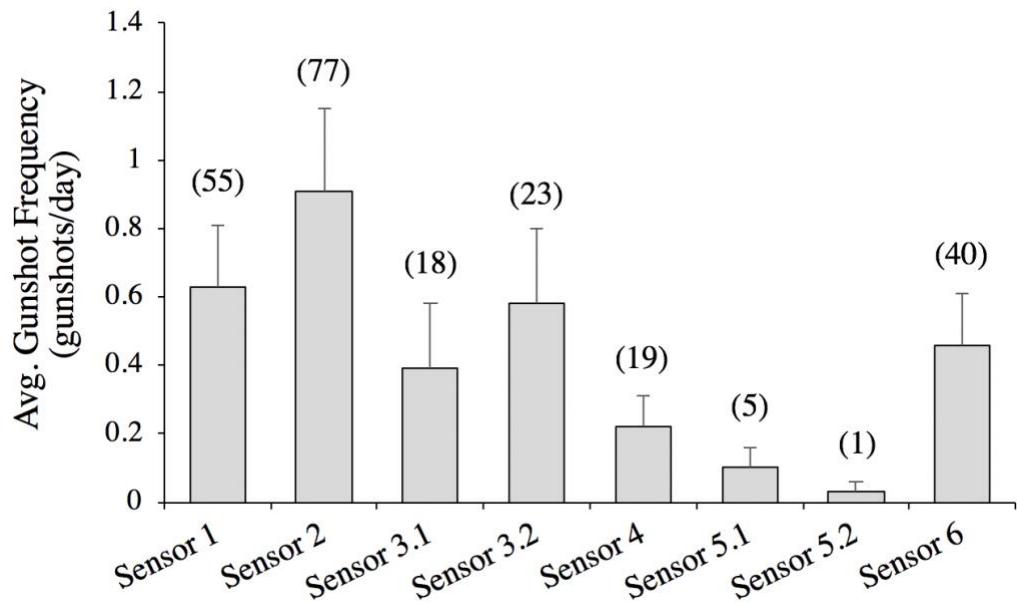


Figure 3.10. Avg. gunshot frequency (gunshots/day) for each acoustic sensor. Numbers above bars indicate the total number of gunshots recorded for each sensor.

3.3.7 Passive acoustic monitoring: gunshot temporal distribution

Gunshots increased after dark and decreased after dawn (Figure 3.11). 34% of gunshots occurred during the day and 66% of gunshots occurred during the night (Table 3.16).

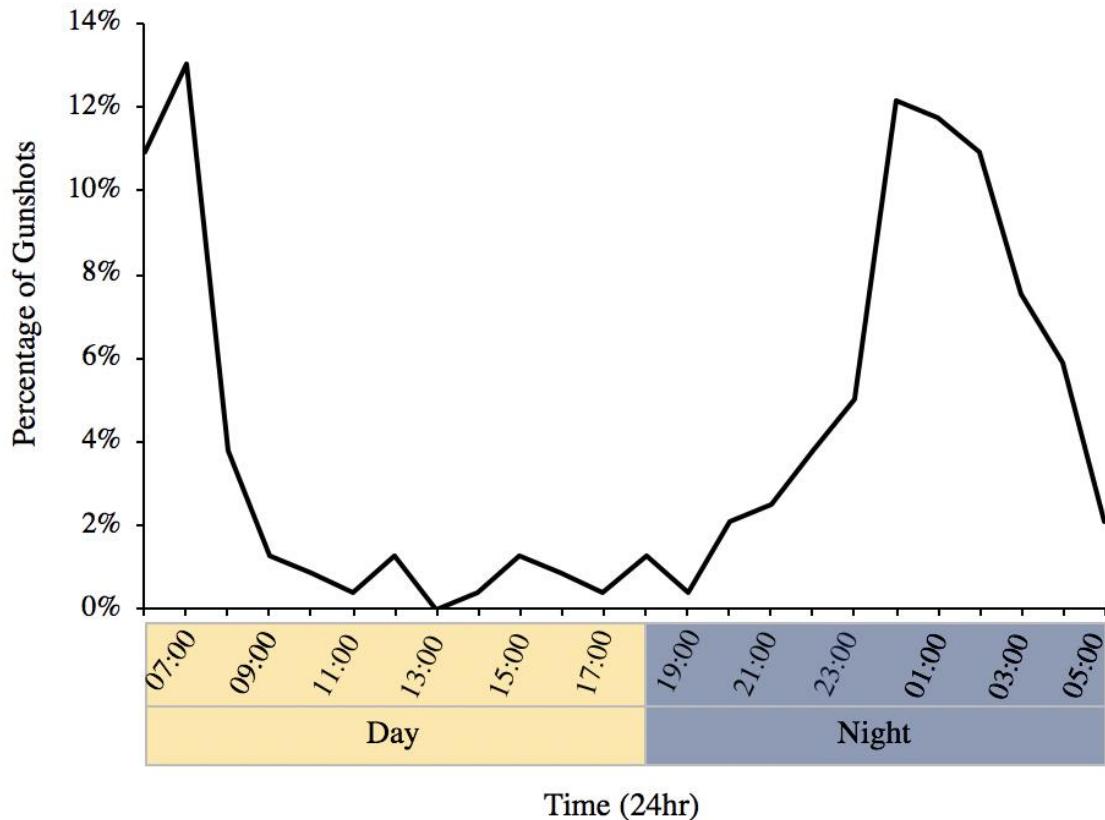


Figure 3.11. The percentage of total gunshots recorded during daylight hours (06:00 – 18:00) and during night hours (18:01 – 05:59) by passive acoustic monitoring sensors in the Ndokbou forest.

Table 3.16. The total number and overall percentage of gunshots recorded during daylight hours and during night hours across all passive acoustic monitoring sensors.

| | Daylight Hours (06:00 – 18:00) | Night Hours (18:01 – 05:59) |
|-------------------------------|---|--|
| No. of gunshots | 82 | 156 |
| Overall Percentage (%) | 34 | 66 |

Gunshot frequency was not significantly different when compared among days of the week (Monday – Sunday) (Kruskal-Wallis, $X^2 = 5.094$, df = 6, p = 0.53). However, Thursday exhibited the greatest overall gunshot frequency with Sunday and Monday having the lowest gunshot frequencies (Table 3.17). In addition, Thursday comprised 40% of all gunshots recorded and was two times greater than the next highest percentage, which was Wednesday (Figure 3.12). Saturday through Monday comprised the smallest percentages of gunshots and the lowest overall gunshot frequencies.

Table 3.17. Gunshot frequency (gunshots/day) for each day of the week of passive acoustic monitoring recording in the Ndokbou forest.

| | Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|-------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| No. of gunshots | 6 | 7 | 27 | 47 | 96 | 44 | 11 |
| Total recording effort (days) | 74.05 | 75.03 | 73.07 | 73.02 | 72.09 | 72.61 | 75 |
| Gunshot frequency | 0.08 | 0.09 | 0.37 | 0.64 | 1.33 | 0.61 | 0.15 |
| Standard error | 0.05 | 0.07 | 0.18 | 0.35 | 0.61 | 0.30 | 0.08 |

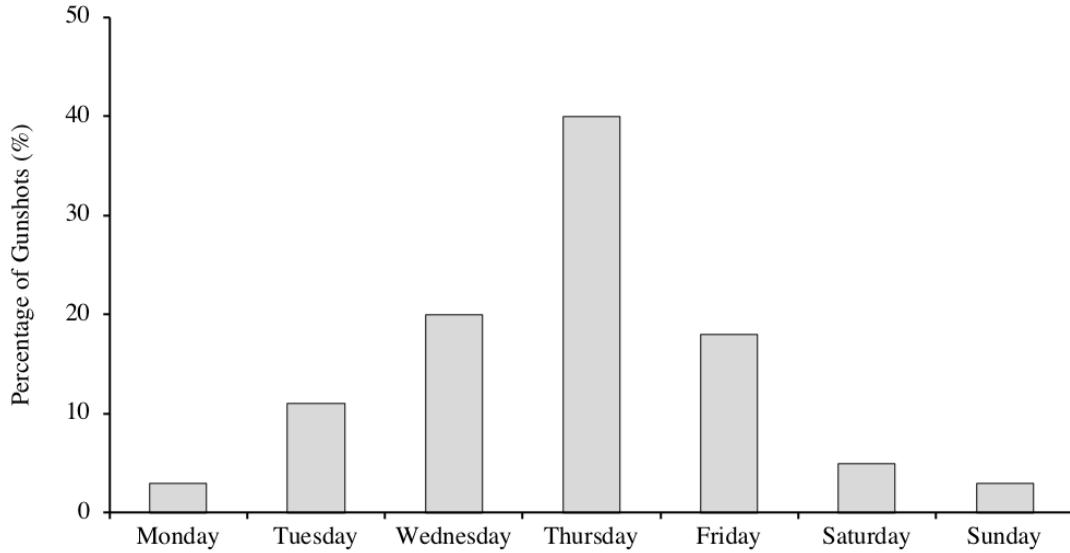


Figure 3.12. The percentage of total gunshots recorded by passive acoustic monitoring sensors for each day of the week in the Ndokbou forest.

While there was no significant difference of gunshot frequency compared among recording weeks (Kruskal-Wallis, 14.794 , $df = 13$, $p = 0.32$) (Table 3.18), there was a positive correlation between recording week number and gunshot frequency (Spearman's correlation, $r_s = 0.48$, $p = 0.08$). With respect to the seasonal periods of the Ndokbou forest, gunshot frequency was lowest during weeks of the rainy season and increased with each recording week progressing into the dry season (Figure 3.13). The second highest peak in gunshot frequency occurred the week of December 9th - 15th with a slight decrease the following week. However, a marked decrease to 0.00 gunshots/day occurs the very last recording week between December 23rd and December 29th.

Table 3.18 Gunshot frequency (gunshots/day) for each week of acoustic monitoring recording during 2019 in the Ndokbou forest.

| Week # | Dates (mm/dd) | No. of gunshots | Total recording effort (days) | Gunshot frequency | Standard error |
|---------------|----------------------|----------------------------|--|------------------------------|---------------------------|
| 1 | 09/23 – 09/29 | 0 | 8.42 | 0.00 | N/A |
| 2 | 09/30 – 10/06 | 7 | 39.57 | 0.17 | 0.12 |
| 3 | 10/07 – 10/13 | 0 | 42 | 0.00 | N/A |
| 4 | 10/14 – 10/20 | 7 | 42 | 0.17 | 0.17 |
| 5 | 10/21 – 10/27 | 29 | 42 | 0.69 | 0.34 |
| 6 | 10/28 – 11/03 | 2 | 42 | 0.05 | 0.05 |
| 7 | 11/04 -11/10 | 22 | 42 | 0.52 | 0.26 |
| 8 | 11/11 – 11/17 | 17 | 40.38 | 0.43 | 0.31 |
| 9 | 11/18 – 11/24 | 25 | 36.6 | 0.69 | 0.56 |
| 10 | 11/25 -12/01 | 38 | 42 | 0.90 | 0.50 |
| 11 | 12/02 – 12/08 | 32 | 42 | 0.76 | 0.43 |
| 12 | 12/09 – 12/15 | 34 | 42 | 0.81 | 0.46 |
| 13 | 12/16 – 12/22 | 25 | 41.53 | 0.61 | 0.33 |
| 14 | 12/23 – 12/29 | 0 | 12.41 | 0.00 | N/A |

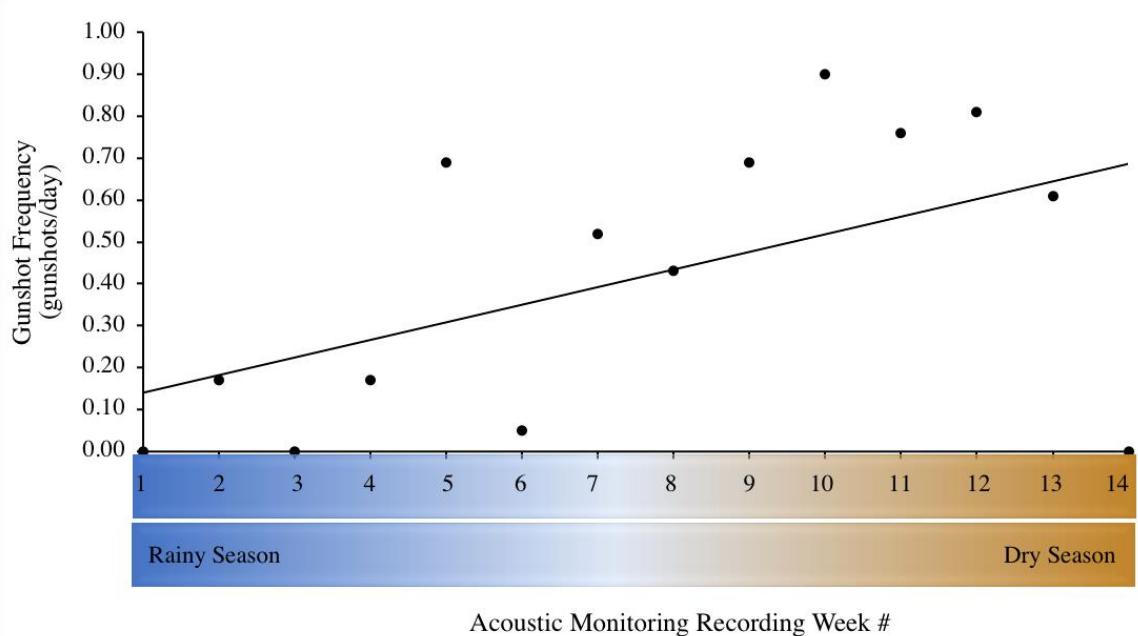


Figure 3.13. Gunshot frequency (gunshots/day) for each week of acoustic monitoring recording with reference to periods of the rainy and dry season in the Ndokbou forest.

When I compared monthly gunshot frequencies there was not a significant difference at the 0.05 level (Kruskal-Wallis, $X^2 = 6.31$, df = 3, p = 0.10). However, November and December had more than two times the gunshot frequency than the months of September and October (Table 3.19).

Table 3.19. Gunshot frequency (gunshots/day) for each month of acoustic monitoring recording during 2019 in the Ndokbou forest.

| | September | October | November | December |
|-------------------------------|-------------|-------------|-------------|-------------|
| No. of gunshots | 2 | 43 | 100 | 93 |
| Total recording effort (days) | 12.45 | 185.49 | 172.98 | 143.94 |
| Gunshot frequency | 0.15 | 0.23 | 0.57 | 0.65 |
| Standard error | 0.14 | 0.10 | 0.20 | 0.18 |

3.3.8 Passive acoustic monitoring: gunshot frequency comparison to Korup NP

When I compared the overall gunshot frequency between the Ndokbou forest and Korup National Park, the Ndokbou forest had a lower gunshot frequency at 0.46 gunshots/day compared to Korup NP with 0.55 gunshots/day. Over the course of two years Korup National Park recorded an average of 40.72 gunshots/year/km², whereas gunshot frequency data from the Ndokbou forest estimates an average of 19.67 gunshots/year/km². However, hourly, daily, and seasonal comparisons were very similar between the two forests. Korup NP acoustic data showed that 69% of gun hunting was occurring at night and the highest percentage of gun hunting occurred during weekdays with smaller percentages on weekend days (Astaras et al. 2017) (Figure 3.14). Additionally, Korup NP acoustic data showed that the greatest gun hunting frequency was occurring during the dry season months between November and January (Figure 3.15). Moreover, Figure 3.16 shows a similar increasing trend line between the months of September and December when comparing gunshots/sensor/month between Korup National Park and the Ndokbou forest.

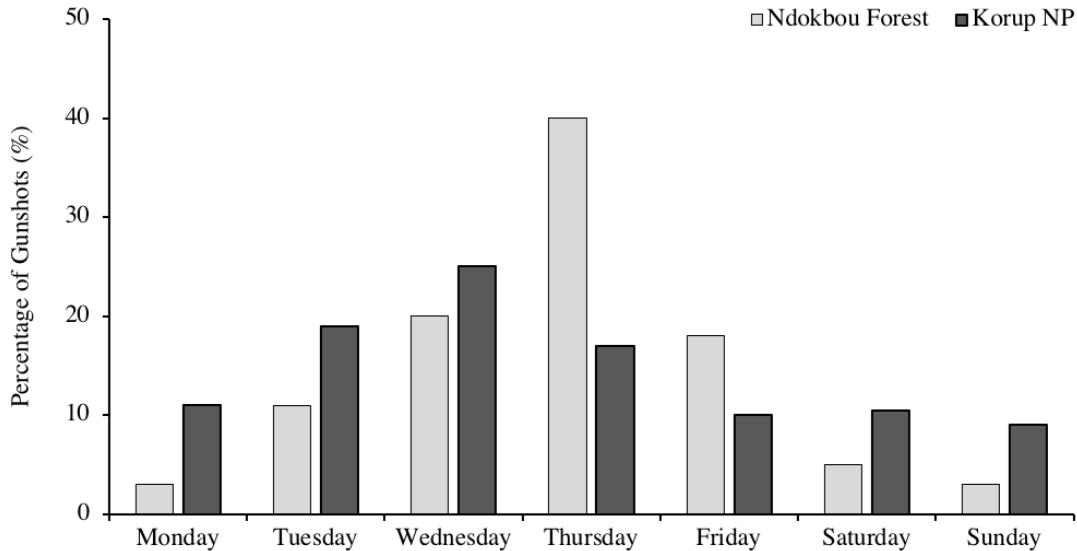


Figure 3.14. Comparison of percentage of gunshots recorded for each day of the week by passive acoustic monitoring between the Ndokbou forest and Korup National Park (adapted from Astaras et al. 2017; J. Linder pers. comm.).

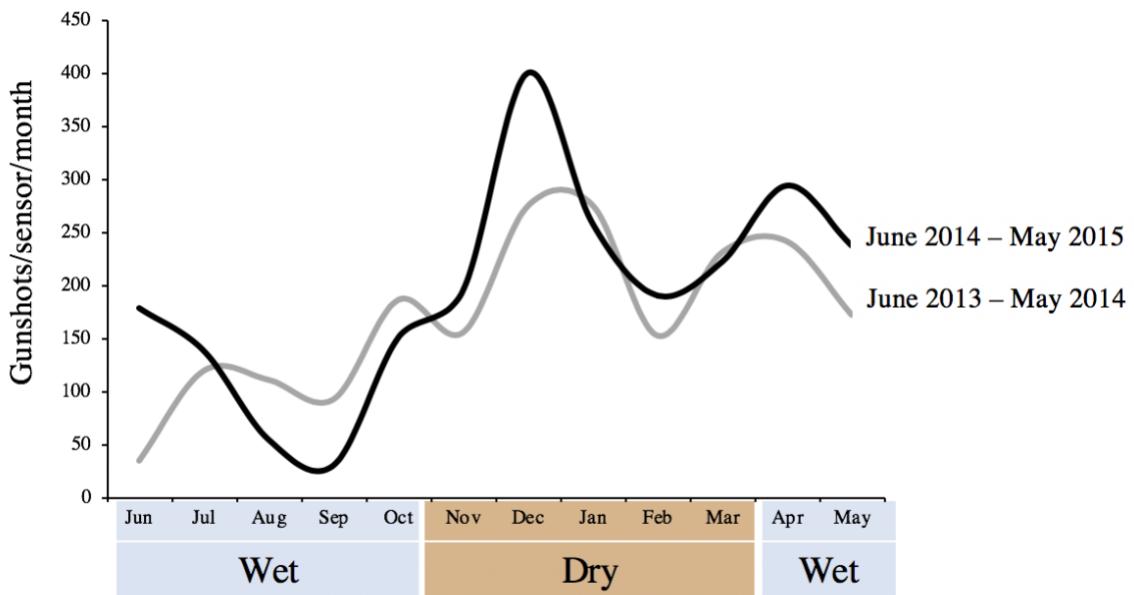


Figure 3.15. Korup National Park monthly gunshot frequencies in 2014-2015 with reference to the wet season and dry season from passive acoustic monitoring data (adapted from Astaras et al. 2017).

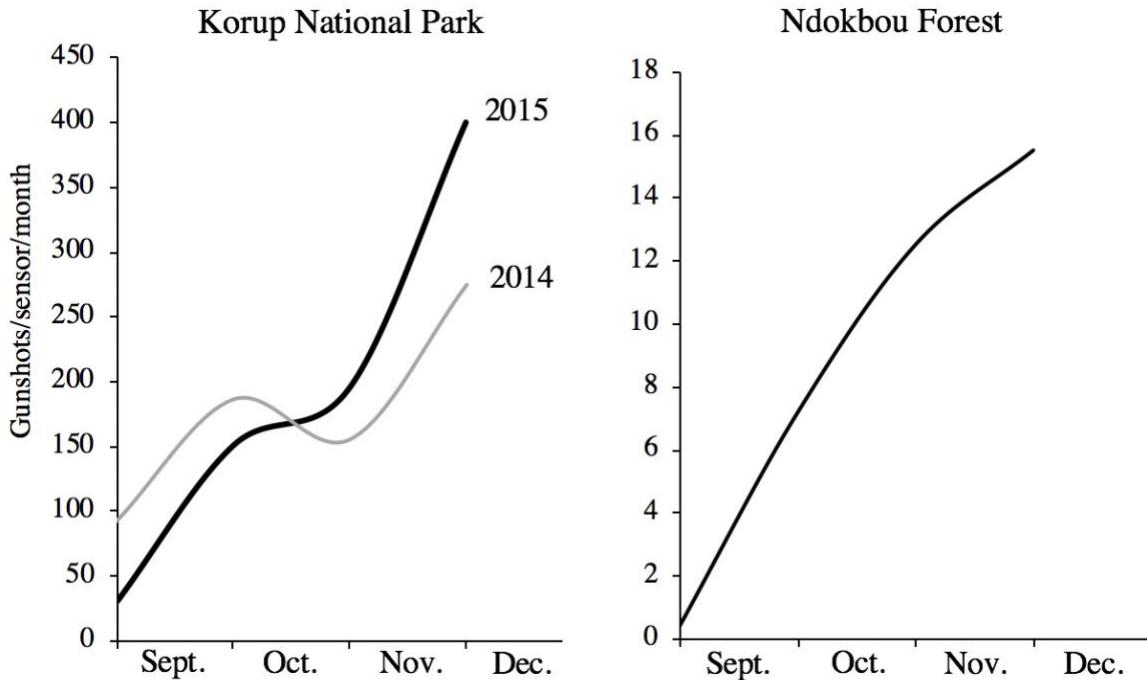


Figure 3.16. Comparison of gunshots/sensor/month recorded by acoustic sensors in Korup National Park (adapted from Astaras et al. 2017) and the Ndokbou forest.

3.3.9 Logging encounter frequency

I encountered a total of 244 logging signs during the 2019 surveys (Figure 3.17). The overall average logging encounter rate for the Ndokbou forest was 1.11 signs/km (S.E. = 0.06). There was a significant difference when comparing logging encounter rates between survey grids (Kruskal-Wallis, $X^2 = 23.091$, df = 6, $p < 0.001$). Grids 34, 3, and 26 exhibited significantly greater logging encounter rates than grid 20, which had no logging sign encounters (Table 3.20). In addition, Grid 3 had a significantly greater logging encounter rate than grid 19.

There was also a significant difference when comparing the encounter rate of each type of logging sign (Kruskal-Wallis, $X^2 = 50.35$, df = 7, $p < 0.001$). Roads had the greatest encounter rate with a significantly greater rate compared to all other logging signs except for cut stumps, cut logs, and tree markings (Table 3.21). Cut stumps had the next greatest encounter rate with a significantly greater rate compared to sounds, loading areas, and camps.

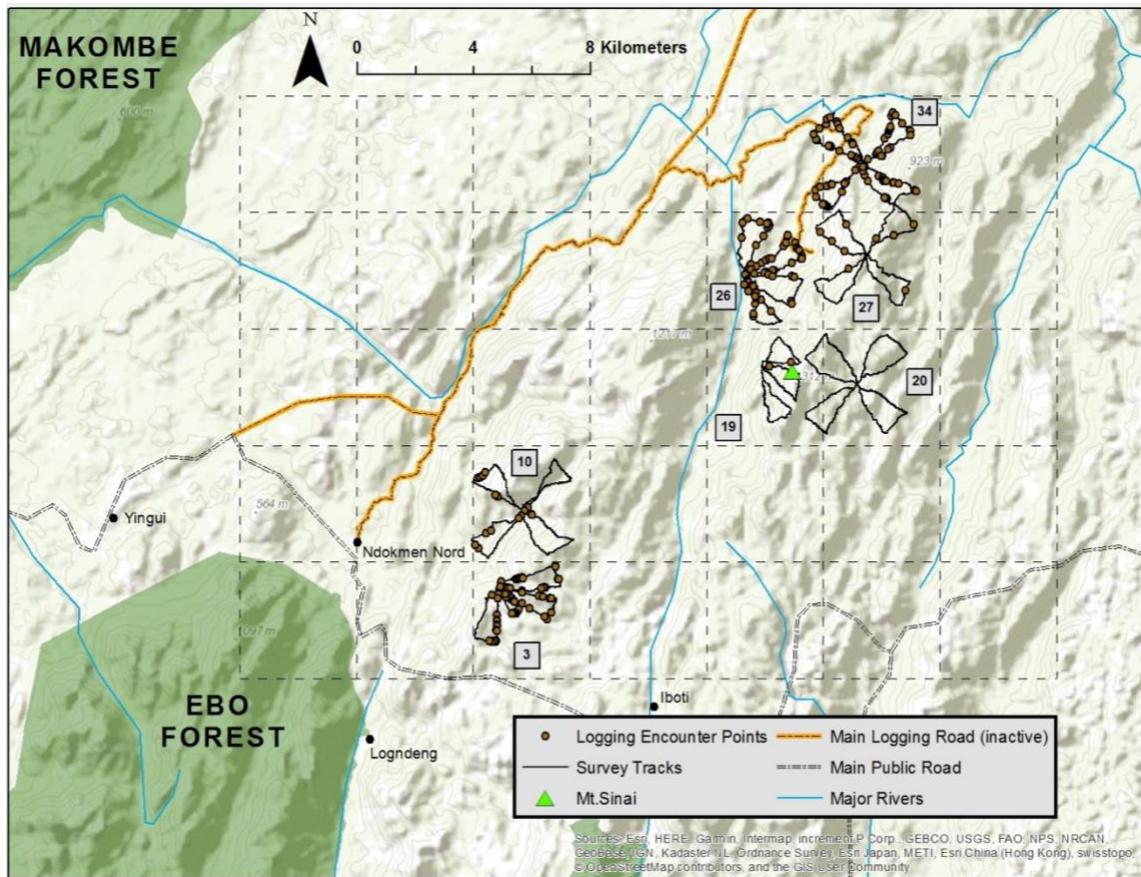


Figure 3.17. All logging sign encounters during 2019 surveys in the Ndokbou forest with reference to survey grid numbers in gray boxes.

Table 3.20. Logging encounter rate (signs/km) for each 2019 survey grid.

| | Grid 3 | Grid 10 | Grid 19 | Grid 20 | Grid 26 | Grid 27 | Grid 34 |
|--------------------------------|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of logging sign encounters | 75 | 16 | 2 | 0 | 58 | 10 | 83 |
| Encounter rate | 2.55 | 0.45 | 0.09 | 0.00 | 1.90 | 0.30 | 2.35 |
| Standard error | 0.21 | 0.12 | 0.05 | N/A | 0.39 | 0.08 | 0.08 |

Table 3.21. Logging encounter rate (signs/km) for each type of logging sign.

| | Road | Cut Stump | Cut Log | Tree Marking | Boundary Tree | Camp | Sounds | Loading Area |
|-----------------------|-------------|-------------|-------------|--------------|---------------|--------------|--------------|--------------|
| No. of encounters | 99 | 72 | 17 | 35 | 12 | 2 | 2 | 5 |
| Encounter rate | 0.45 | 0.33 | 0.08 | 0.16 | 0.05 | 0.009 | 0.006 | 0.02 |
| Standard error | 0.21 | 0.14 | 0.03 | 0.08 | 0.08 | 0.009 | 0.006 | 0.02 |

I conducted two PCA's first to narrow down logging signs to the most influential signs and then to analyze the effects of the new cohort of logging signs on survey grid logging encounter rates. Results from the first PCA using all logging signs showed a PC1 proportion of variance of 56.16% and the top three most influential logging signs being cut stumps (-0.47), cut logs (-0.44), tree markings (-0.36), loading areas (-0.36), camps (-0.35), and roads (-0.33) (Figure 3.18). I then used these logging signs to conduct the second PCA which had a total cumulative variance of 96.7% between PC1 and PC2. This PCA indicated that grids 19, 20, and 27 were not largely influenced by any particular type of logging sign (Figure 3.19). Grids 26 and 3 were most affected by roads and grid 34 by tree markings, camps, and loading areas. No one grid was largely influenced by cut stumps or cut logs.

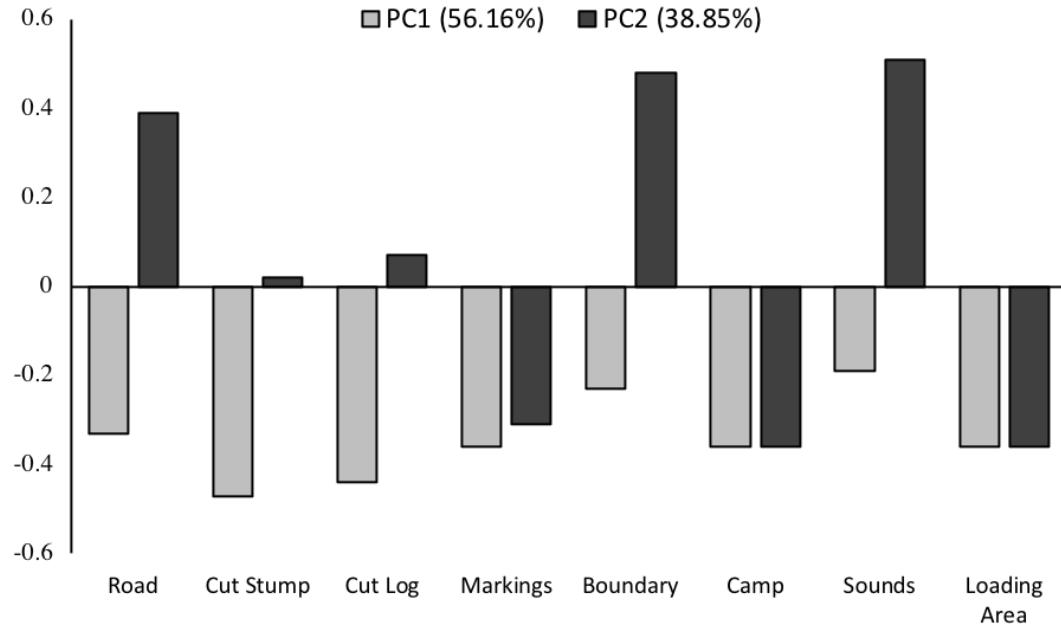


Figure 3.18. Principal component analysis results of PC1 and PC2 using the encounter frequency of all logging signs on survey grids.

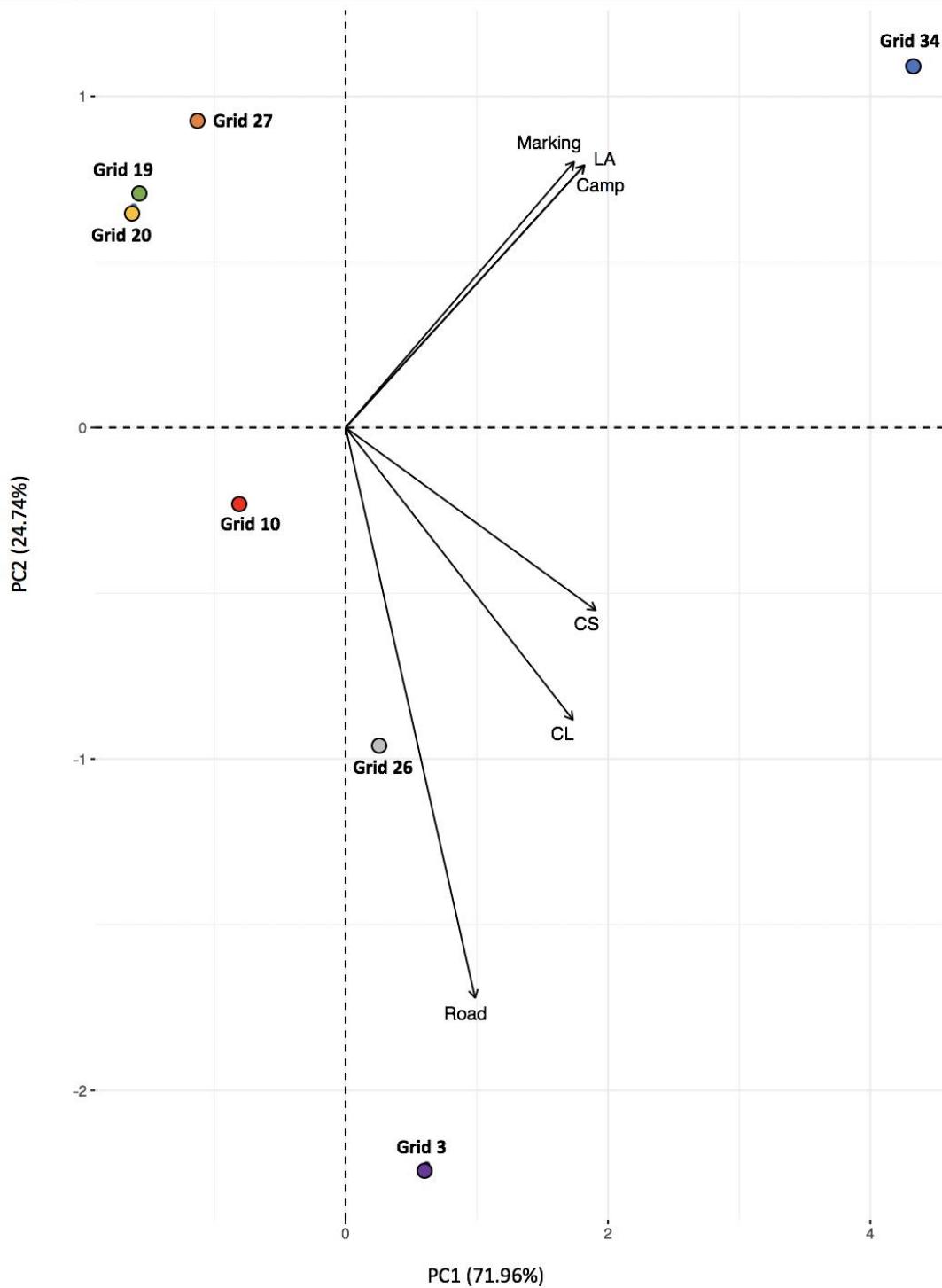


Figure 3.19. Principal component analysis conducted using the six most influential logging signs on survey grids. Logging signs include tree markings (“Marking”), loading areas (“LA”), logging camps (“camp”), cut stumps (“CS”), cut logs (“CL”), and logging roads (“Road”).

3.3.10 Combined hunting and logging encounter frequency and distribution

When I reviewed the combined hunting and logging sign encounters from 2019 survey data, I encountered a total of 349 signs (excluding trails) over the course of 219.45 km surveyed, resulting in an overall encounter rate of 1.59 signs/km (S.E. = 0.24) of human activity in the Ndokbou forest. There was a significant difference when comparing the encounter rates between survey grids (Kruskal-Wallis, $X^2=19.512$, df = 6, p = 0.003). Grid 3 with the largest encounter rate, exhibited a significantly greater encounter rate than grid 20 with the lowest encounter rate (Table 3.22). The next largest encounter rate was exhibited by grid 34.

The PCA using hunting and logging encounters for each survey grid indicated that grid 34 is most heavily affected by logging encounters while grids 10, 19, 20, and 27 are more affected by hunting encounters (Figure 3.20). Grids 3 and 26 are influenced by both hunting and logging encounters.

Table 3.22. Encounter rates (encounter/km) for combined hunting and logging signs of each 2019 survey grid in the Ndokbou forest.

| | Grid 3 | Grid 10 | Grid 19 | Grid 20 | Grid 26 | Grid 27 | Grid 34 |
|------------------------|---------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Distance surveyed (km) | 29.38 | 35.33 | 22.53 | 32.92 | 30.54 | 33.36 | 35.39 |
| No. of encounters | 94 | 36 | 20 | 16 | 71 | 20 | 92 |
| Encounter rate | 3.20 | 1.20 | 0.89 | 0.49 | 2.32 | 0.60 | 2.60 |
| Standard error | 0.28 | 0.30 | 0.36 | 0.30 | 0.47 | 0.15 | 0.13 |

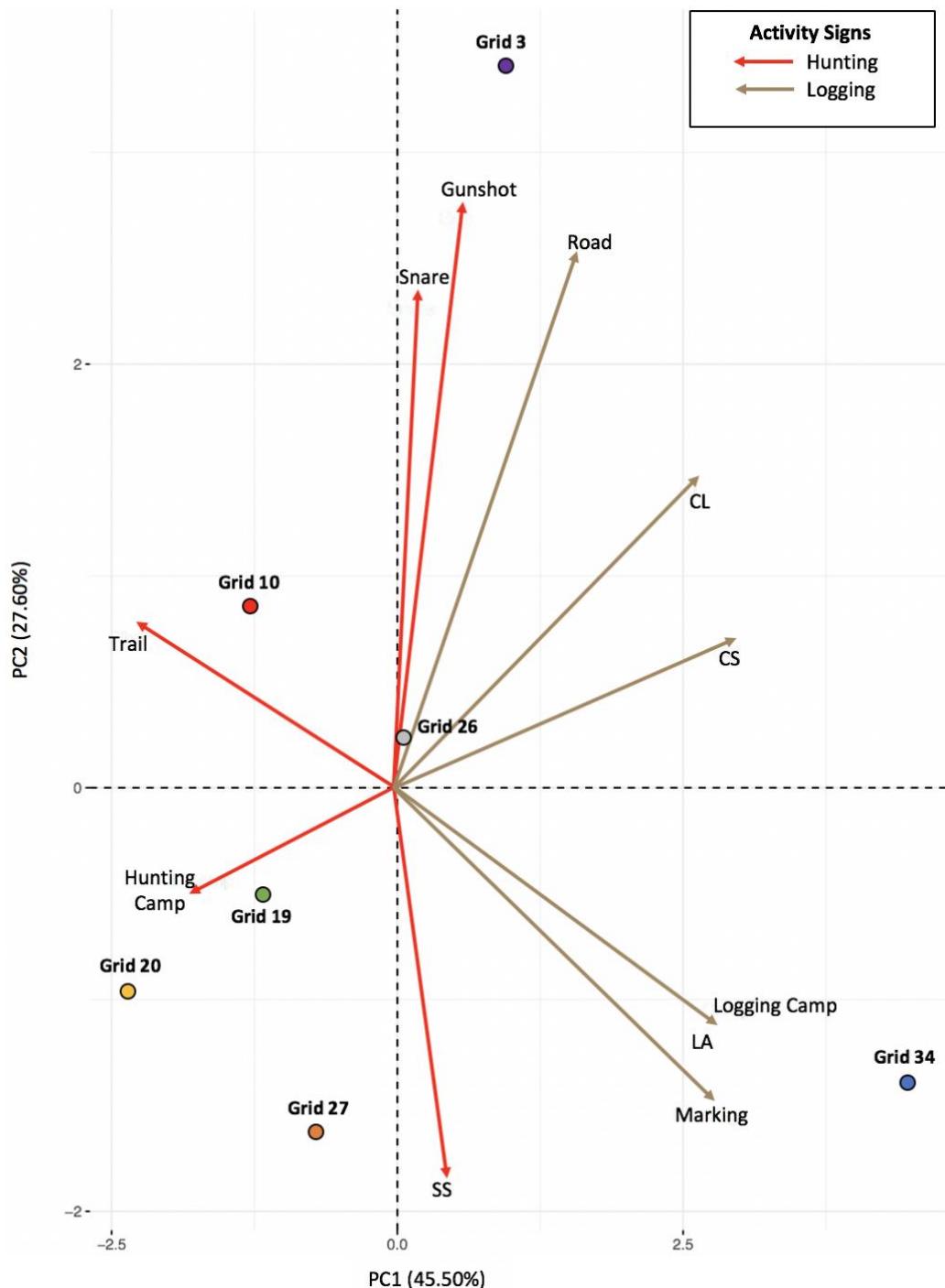


Figure 3.20. Principal component analysis using hunting and logging sign encounters in 2019 survey grids. Hunting signs include: Gunshots heard (“Gunshot”), snare traps (“Snare”), hunting trails (“Trail”), hunting camps (“Hunting camp”), and shotgun shells (“SS”). The six most influential logging signs were used, which includes: tree markings (“Marking”), logging camps (“Logging Camp”), cut stumps (“CS”), cut logs (“CL”), and logging roads (“Roads”).

3.4 Discussion

3.4.1 Hunting activity in the Ndokbou forest

Hunting signs encountered during forest surveys were widespread in the Ndokbou forest and, contrary to my prediction, there was no significant difference in the geographic distribution of hunting sign encounter rates. Survey grid 19, where Mt. Sinai is located, exhibited overall the largest hunting sign encounter rate. However, when reviewing the composition of hunting sign types in grid 19, remnant pit-fall traps (a hunting method no longer in use) exhibited the largest hunting sign encounter rate. While grid 19 actually exhibited the lowest gun hunting sign (shotgun shells and gunshots heard) encounter rate of any grid. In addition, results from the terrain parameters of hunting sign encounters indicate that pit-fall traps were found on significantly more rugged terrain and on some of the highest elevations of the forest compared to all other hunting signs. This coincides with the Mt. Sinai region having some of the most rugged terrain and grid 19 containing the highest encounters of pit-fall traps.

Grids 3 and 10, which are located closest to villages found on the southwest border of the Ndokbou forest, exhibited the next largest overall hunting sign encounter rates after grid 19. These grids also exhibited some of the largest gun hunting sign encounter rates with the largest encounter rates of snare traps. In addition, grid 10 had the largest encounter rate of hunting trails. While grid 19 exhibited the largest hunting sign encounter rate due to pit-fall traps heavily weighing results, grids 3 and 10, which are located closest to villages and main roads exhibited the largest gun hunting sign encounters.

An important finding however, is that grids 34 and 26, which are located farthest from the villages and main public road, exhibited nearly identical gun hunting sign encounter rates as grids 3 and 10. Grids 34 and 26 contained some of the highest encounter rates of shotgun shells and the lowest encounter rates of trails and snare traps. This could be attributed to the fact that a main logging road, most recently active in 2017, leads directly from the villages of Yingui and Ndokmen Nord into grids 34 and 26.

Studies have shown that logging roads are often utilized by hunters (Fa et al. 2005; Laurance et al. 2006, 2009; Wilkie et al. 2011), which may help to explain why the lowest frequency of hunting trail encounters are in this region as the main logging road, including smaller secondary roads from the main road, may provide routes for hunters through the forest rather than trails. And considering these grids are located farthest from villages, hunters may more readily utilize gun hunting rather than snare trapping, which would require having to set up traps and repeatedly re-visit them to check for wildlife. When comparing the geographic characteristics of hunting signs, shotgun shells were also encountered significantly farther from villages and main public roads than all other hunting signs, which supports findings that the farthest grids have equal to more gun hunting activity than grids located closest to villages and public roads.

Grids 3, 10, 34, and 26 all exhibited similar gun hunting sign encounter frequencies, however, grid 27 actually exhibited the largest gun hunting sign encounter rate. And when reviewing the map of all gun hunting sign encounters, many hunting signs are clustered along a single prominent ridgeline that connects the southeast portion of grid 34 into the northeast portion of grid 27. This may indicate hunters are accessing previously hard-to-reach regions of the forest via logging roads and following the natural topography to access other rugged regions of the forest.

When comparing types of hunting signs overall, hunting trails were by far the most frequently encountered sign and were heavily weighing hunting sign encounter rates. In addition, hunting trails had the largest range of distances from villages, main public roads, and main logging roads indicating these trails occur throughout the Ndokbou forest, near and far from human habitation and activity. However, it's difficult to know if a trail encounter is a continuation of the same trail from another trail encounter or if it is truly a separate trail. It is also difficult to know how recently a trail has been used or for how long it has been in use. Therefore, my overall hunting sign encounter comparisons were conducted excluding trail encounters.

When excluding hunting trails, snare traps were by far the most frequently encountered hunting sign with shotgun shells being the next most frequently encountered hunting sign. This supports findings from Fuashi *et al* (2019), who also found that guns and wire snare traps were the most commonly used hunting methods in the Ebo forest. However, gunshots heard - the only direct sign of gun hunting - was the least encountered hunting sign during forest surveys in the Ndokbou forest.

Subsequently, when comparing gun hunting activity between forest recce surveys and passive acoustic monitoring, a total of 28 gun hunting signs (gunshot shells and gunshots heard) were encountered during forest surveys, while acoustic monitors recorded a total of 238 gun hunting events. I was able to further use acoustic monitoring data to extrapolate an estimate of 19,668 gunshots across the entire area of the Ndokbou forest each year. In addition, when comparing the geographic distribution of gun hunting as identified from these two methods, acoustic sensor data showed higher levels of gun hunting in grid 10 compared to grid 20, while recce surveys failed to do so. This supports findings from Astaras *et al* (2017) that similarly found that acoustic sensors were able to show a 12% increase in gun hunting activity while traditional forest surveys did not show any difference in gun hunting frequency. Ultimately, acoustic monitoring methods provided more detailed information on the amount and distribution of gun hunting activity by showing greater levels of gun hunting occurring in the Ndokbou forest than forest survey methods, supporting my prediction.

Overall, the spatial distribution of gun hunting activity as identified by acoustic monitoring methods showed that forest regions encompassing Mt. Sinai, which includes some of the most mountainous regions and highest elevation points of the Ndokbou forest had the lowest levels of gun hunting. This further supports my prediction that terrain variables associated with more difficult access into regions of the forest including high elevations, large slopes, and a lack of logging roads allowing for easy access may be impeding hunting activities in the Mt. Sinai region of the Ndokbou forest.

3.4.2 Temporal patterns of gun hunting

Acoustic sensor data showed that gun hunting was highest during the night, supporting findings from Astaras *et al* (2017), that also found the greatest gun hunting activity occurred during the night in Korup NP. Results also indicate a large peak of gun hunting activity between 06:00 and 0:700. This period during the morning is an important time of activity for primates when they are often heard vocalizing and making movements from sleeping sites during the early morning hours, which may explain this peak in gun hunting activity.

In addition, acoustic data demonstrated that the greatest gunshot frequency occurred on Thursdays, while weekends exhibited the lowest gunshot frequency. This also supports Astaras *et al* (2017) who found that gun hunting was most prevalent during the week on days leading up to market days. At the time of this study, the village of Yingui had its major market day on Saturdays and then another market day on Tuesdays. This coincides with findings from this study that gun hunting is greatest Wednesday-Friday leading up to the market day on Saturday and after the Tuesday market day.

Acoustic data also demonstrated a positive correlation between gunshot frequency and recording week number. Increasing weeks of recording coincide with the transition from the rainy season occurring between week 1 and approximately week 7 into the dry season from approximately week 8 through week 14. There was no statistically significant difference between average monthly gunshot frequency estimates, however the months of November and December showed greater gunshot frequency than September and October. These findings support Astaras *et al* (2017) who also found that the rainy season months in Korup National Park exhibited lower gun hunting activity compared to dry season months.

In regard to weekly averages, there was a peak in gunshot frequency between December 9_{th} – 15_{th} with a slight decrease the following week and then a drastic drop to zero gunshots the week of December 23_{rd} – 29_{th}. This timing coincides with the Christmas holiday as hunting activity

may increase during the weeks leading up to the week of Christmas in order to earn more income and provide bushmeat for the holiday (Tieghong & Zwolinski, 2009; Gardner & Davies, 2013).

Subsequently, the week of Christmas day, no gun hunting was recorded. Astaras *et al* (2017) similarly found peaks in gun hunting activity the week leading up to Christmas day.

3.4.3 Hunting comparison between forests

Contrary to my prediction, hunting sign encounter data from forest surveys compared between the Ndokbou-Makombe forests and Korup NP show that the northeast region of Korup NP exhibited a greater hunting sign encounter rate compared to both Ndokbou and Makombe forests. However, the southern region of Korup NP had a noticeably lower hunting encounter rate than the Ndokbou and Makombe forests. Linder (2008) noted that southern Korup is located closer to research and tourist activity, which may explain the distinct lower levels of hunting activities in that region compared to Ndokbou and Makombe. The larger encounter rate of hunting in northeastern Korup NP compared to Ndokbou-Makombe may be attributed to a high demand for bushmeat coming from the high population densities in Nigeria (Fa *et al.* 2006; Macdonald *et al.* 2012) and higher human population densities surrounding the Korup region compared to the Ndokbou and Makombe forest region. These findings are also supported with acoustic sensor gunshot frequency data results showing that Korup NP has a greater mean gunshot frequency per day and a greater mean annual gunshot frequency/km² than that of the Ndokbou forest.

Comparison of hunting sign types show that gun hunting signs are encountered more frequently in Korup NP than in Ndokbou-Makombe where snare traps had much larger encounter rates. This also coincides with results showing Korup NP exhibiting a larger gunshot frequency than the Ndokbou forest. However, the extremely low encounter rates of snare traps in Korup NP may be attributed to the fact that Linder (2008) conducted line transect surveys and hunters would avoid placing snare traps on transects (J. Linder pers. comm.).

3.4.4 Logging activity in the Ndokbou forest

My results indicate that logging sign encounter rates are largest near villages and roads, supporting my prediction. Grid 3 and 34 exhibited by far the largest logging sign encounter rates. Grid 3 is located closest to the main public road and the village of Ndokmen Nord. While the main logging road intersects through grid 34 and into grid 26, which exhibited the next largest logging sign encounter rate.

Grids 19 and 20 exhibited the lowest logging encounter rates. Notably, grid 19 encompassing Mt. Sinai exhibited two total logging signs, one of which was a tree marking the boundary of an assiette de coupe and the other being a tree with an “X” inventory marking. Moreover, no signs of previous active logging (e.g. cut stumps or logging roads) were encountered in grid 19. Grid 20 exhibited zero logging signs and was the only survey grid to do so. As previously noted, the regions containing Mt. Sinai are least accessible to humans due to terrain and topography. This may explain the absence of logging in grids 19 and 20 due to increased difficulty and inaccessibility for road construction to transport logging equipment. However, boundary and inventory tree markings in grid 19 may indicate that either the assiette de coupe has simply not been permitted yet for logging and/or the results from inventorying tree species were not adequate for bringing logging operations into that region. But ultimately, the logging signs encountered in grid 19 indicate that it was being considered for active logging but with no logging subsequently taking place. Grid 20 has no indication of inventories taking place or active logging boundaries being present.

In terms of logging signs encountered, roads were the most encountered logging sign in the Ndokbou forest with cut stumps being the next most encountered sign. Results from the logging sign PCA indicate that logging encounters in grids 26 and 3 are most heavily influenced by logging roads and that cut stumps and cut logs are not heavily influencing logging abundance in any particular grid. These results highlight a large infrastructure of logging roads present in the Ndokbou forest, in regions both near and far from human settlements.

Chapter 4: Conclusions

4.1 Summary of Findings

The Ebo-Makombe-Ndokbou forest block falls within the Gulf of Guinea rainforest region known for extremely high levels of species richness and diversity (Oates et al. 2004). This region is particularly important for a number of Threatened primate species including *P. t. ellioti*, *M. leucophaeus*, *Allochrocebus preussi* and the Critically Endangered *Piliocolobus preussi* (Morgan et al. 2011). However, human pressures including hunting and habitat degradation from selective logging and agricultural expansion have been occurring for decades throughout these forests (Dowsett-Lemaire & Dowsett, 2001; Singer 2008; Morgan et al. 2011; Cerutti et al. 2015). These forests have no formal protection status (although the Ebo forest has been proposed as a national park) and, outside of the Ebo forest, have received limited research on the possible effects of human pressures on primate abundance. Therefore, our current knowledge on the extent and abundance of primate species and Preuss's red colobus in particular is relatively unknown for these forests, including and especially the Ndokbou forest. Through the use of traditional forest survey methods and novel passive acoustic monitoring methods, the goals of this study were to assess the population status of and threats to Preuss's red colobus and other diurnal primates in the Ndokbou forest and to assess the utility of passive acoustic monitoring as a conservation tool to determine levels of gun hunting and the presence of rare primate species.

The first aim of this study was to assess the distribution and relative abundance of Preuss's red colobus and other diurnal primates found in the Ndokbou forest and compare these with distribution and abundance estimates found in Korup National Park. I had no sightings of *P. preussi* and a single vocalization encounter in the region closest to Mt. Sinai. This supported my predictions and showed that Preuss's red colobus was present in the Ndokbou forest nearest to Mt. Sinai. It is important however, to make the distinction that an indirect vocalization merely suggests that *P. preussi* are present but a sighting, especially with photographic evidence is the

best verification for confirming absolute presence. But in consideration of the one vocalization encounter, the population abundance estimate for *P. preussi* was lower than the population abundance of *P. preussi* found in Korup National Park. Overall primate abundance of almost every primate species was greater in the protected Korup National Park than in the Ndokbou and Makombe forests, highlighting an overall low abundance of primates in the Ndokbou-Makombe forests.

I did not find any statistical association between overall primate abundance and geographic variables in the Ndokbou forest, contrary to my predictions. However, *Cercopithecus* spp. and *C. nictitans* in particular, were the most widespread species, with encounters in every region of the forest, near and far from human habitation and activities such as villages and logging roads. I only sighted two of the larger-bodied primate species, *A. preussi* and *M. leucophaeus*, and I did not have any sightings of *P. t. ellioti*, *C. torquatus*, or *P. preussi*. The regions where there were *P. t. ellioti*, *M. leucophaeus*, and *A. preussi* encounters (sightings or vocalizations) were at the greatest elevations with the largest slopes. These species were also encountered at some of the largest distances from villages and roads.

These findings are related to results addressing the second aim of my study, which was to assess the geographic distributions of hunting and logging threats in the Ndokbou forest. Hunting results showed that while overall hunting sign encounters were widespread in the Ndokbou forest, there were only 28 encounters of gun hunting activity over the course of 219.45 km of forest surveys with the lowest encounter rate being in the region encompassing Mt. Sinai. Similarly, logging activity was greatest in regions closest to villages and the main logging road, supporting my predictions. The most mountainous and rugged regions of the forest nearest to Mt. Sinai displayed little to no logging activity.

In addition to forest survey methods used to assess the distribution of hunting activities, acoustic sensor data was used to provide additional trends and assessments of gun hunting activity. Acoustic sensor data showed that there was four times more gun hunting occurring in

grid 10, closest to the village of Ndokmen Nord, than in grid 20 located farthest from Ndokmen Nord. In addition, acoustic data showed a greater prevalence of gun hunting at night and during weekdays leading up to village market days. There was a peak in gun-hunting activity two weeks prior to the Christmas holiday and during the months of November and December, which coincides with the dry season.

4.2 Synergistic Impacts of Logging and Hunting on Primate Abundance

The final aim of this study was to evaluate the relationship between primate abundance and the distribution and frequency of logging and hunting activities in the Ndokbou forest. Previous studies assessing logging impacts on primate abundance reveal that while some primates are negatively impacted by habitat loss and degradation associated with logging, other primate species may thrive in lightly to moderately logged forests (Remis & Jost Robinson, 2012; Chapman et al. 2018). Preuss's red colobus are particularly vulnerable to habitat degradation as they require intact, high canopy primary forests. More generalist species such as *C. nictitans* can thrive in a variety of primary and secondary, disturbed forests. In addition, larger-bodied primates with low intrinsic rates of population increase are also most at risk from hunting activities (Fa & Brown, 2009; Nasi et al. 2011). The Ndokbou forest has a history of logging occurring intermittently since 2005 in various regions throughout the forest (Singer, 2008; Bureau Veritas Certification, 2012; Cerutti et al. 2015) and reports of over-hunting occurring as early as 2001 (Dowsett-Lemaire & Dowsett, 2001). Moreover, when both forms of human impact are present, it is important to assess their synergistic effects, as logging has been shown to lead to increased levels of hunting (Wilkie et al. 2000; Laurance et al. 2006, 2009, 2017), which may impact primate species most at risk from hunting activities.

Results from forest surveys and passive acoustic monitoring indicate a possible relationship between logging roads and the distribution of hunting activities. Gun-hunting encounter rates showed that equal levels of hunting were occurring nearest to the village of

Ndokmen Nord and nearest to the logging road passing through grids 34 and 26, while the Mt. Sinai region had the lowest levels of gun hunting. The region of Mt. Sinai also showed no evidence of active logging or logging roads. While there is no acoustic sensor data for grid 34, acoustic data also showed that similar gunshot frequencies were occurring in grids closest to Ndokmen Nord and in grid 26 nearest to the logging road. These frequencies were relatively high in comparison to grid 20 neighboring the Mt. Sinai region where there was four times less gun hunting.

The main geographic features that naturally restrict human access to the far-reaching Mt. Sinai regions of the Ndokbou forest are the Grand Nouya river and high elevation ridgelines running parallel to the river. During the rainy season (March – November), the Grand Nouya river is not crossable without access to a bridge (EFRP guide pers. comm.). Therefore, any villages located west of the river would be restricted to hunting west of Grand Nouya and outside of the Mt. Sinai region of the forest for much of the year, and it would be reasonable to expect that the least amount of hunting activity would be occurring in regions east of the Grand Nouya river. However, when logging operations began in the Ndokbou forest, roads were constructed from the main village of Yingui into the central region of the forest with bridges crossing many large rivers including Grand Nouya. After logging operations left the region of the forest in 2018, bridges were destroyed over many rivers (pers. obs.), which restricted motorbikes from accessing the main logging road. However, the logging road is still readily accessible via walking and more importantly, the bridge crossing over Grand Nouya was left intact.

Many studies show that logging roads can exacerbate the problem of over-hunting by providing easy access for hunters into the forest (Wilkie et al. 2000; Laurance et al. 2006, 2009, 2017). Results from this study show that similar levels of hunting are in fact occurring closest to villages and closest to the main logging road in grids 26 and 34 located east of the Grand Nouya river. Prior to logging road and bridge construction this region of the forest would have been difficult to access nine months out of the year. This supports findings that logging roads provide

access to the forest for hunting activity and may subsequently lead to increased levels of hunting in regions of the forest previously hard to access (Wilkie et al. 2000; Laurance et al. 2006, 2009, 2017).

We find that there is a widespread presence of *C. nictitans* and *C. p. pogonias* and even some larger-bodied species including *P. t. ellioti* and *A. preussi*. However *P. preussi*, shown to be the most vulnerable species to hunting and logging (Linder & Oates, 2011; Linder, Cronin, and Ting, et al. 2020) is found to be completely restricted to the Mt. Sinai region of the forest where there is an absence of logging roads and the lowest levels of gun hunting. This supports findings from Linder (2008) in Korup National Park where Preuss's red colobus (*P. preussi*) was also found to be declining due to overhunting. The Ebo-Makombe-Ndokbou forest was the likely source of at least 80 of the earliest specimens of Preuss's red colobus. Results from this study suggest that overhunting and logging have nearly extirpated Preuss's red colobus from the Ndokbou forest.

The abundant and widespread presence of *C. nictitans* and *C. pogonias* is another indication that hunting and habitat degradation are suppressing larger-bodied primate species in the Ndokbou forest. *C. nictitans* and *C. pogonias* are found to be highly tolerant of habitat alterations from logging activities, and *C. nictitans* in particular, may actually benefit from the decline of large-bodied primate species where hunting has led to decreases in primate populations (Linder & Oates, 2011; Remis & Jost Robinson, 2012; Albert et al. 2014; Cronin et al. 2016). *C. nictitans* take advantage of a wide range of habitats from mature, primary forests to secondary, degraded forests (Gartlan & Struhsaker, 1972; Oates, 2008). They also are the most folivorous of the guenon species and can easily switch from fruits to leafy materials when there is scarcity of one food type (Gautier-Hion, 2013b). This ecological flexibility allows *C. nictitans* to take advantage of habitats with a wide range of alteration and human activity. In addition, Struhsaker (1978) found that when there was overlap in food habits between red colobus, mangabey species and *Cercopithecus* species in Kibale National Park, Uganda, the removal of the large-bodied

primate food competitors from hunting may have led to increases of *Cercopithecus* populations. In this study for example, *C. nictitans* had the highest encounter rates (excluding *P. t. ellioti* nest encounters) in grids 10, 3, and 27, which had the highest gun hunting sign encounter rates. They also exhibited the largest encounter rate in grid 34, which had the highest logging sign encounter rate. Ultimately, the wide-range distribution and abundance of *Cercopithecus* species in the Ndokbou forest may be a sign that habitat degradation and hunting activities are suppressing large-bodied primate species and allowing for increases in *Cercopithecus* populations.

Other important findings suggesting declines in large-bodied primate species due to increasing hunting activities come from comparisons to primate distribution reports from Dowsett-Lemaire & Dowsett (2001). Dowsett-Lemaire reported vocalizations of *A. preussi* next to the village of Ndokmen Nord. While this species did have the largest sighting and encounter frequency of all large-bodied species, there were no sightings of this species in grids 10 and 3 with only a single vocalization in grid 10, which was the closest encounter to a village. The greatest encounter frequency of this species occurred east of the Grand Nouya river with a notable sighting encounter occurring in grid 19. For approximately 17 minutes I was able to sit with a group of 10-15 *A. preussi*, where they came as close as 10 meters from me and my guide and reached as low as 1 meter off of the ground. Primates that have experienced hunting activities in the forest typically respond to the presence of humans by fleeing or becoming cryptic, however, this group of *A. preussi* appeared to have no apprehension toward the presence of humans. This was the only encounter of its type, which occurred in grid 19 closest to Mt. Sinai, suggesting that this particular group of *A. preussi* did not have much or any experience with hunters in that area.

While the Mt. Sinai region may contain a pocket of low gun-hunting levels with the absence of logging roads, the Ndokbou forest exhibits an overall low primate abundance when compared with Korup National Park. Even the most wide-spread and most abundant primate species in the Ndokbou forest such as *C. nictitans* exhibit less than half the sighting frequency as

C. nictitans found in Korup National Park. This may suggest that the protection status of Korup National Park may in fact be providing some level of protection to primate species from hunting. However, when comparing hunting activity between forests, Korup National Park still exhibits a larger overall hunting sign encounter rate and a noticeably larger gunshot frequency than the Ndokbou forest. These findings may suggest that the region of Korup National Park retains a greater demand for bushmeat with higher human populations surrounding the park and a large demand from dense population centers in neighboring Nigeria. The Ndokbou forest may also be starting to exhibit such low wildlife abundance that it is difficult for hunters to find large-bodied wildlife species that require shotguns to kill. This might explain the relatively low rate of gun hunting as measured by the acoustic sensors and encounter rates of hunting signs. During my time in the village of Ndokmen Nord I heard reports from hunters who were worried that wildlife was becoming scarce in the Ndokbou forest. A more comprehensive evaluation surveying hunters' perspectives on wildlife abundance in the forest would be beneficial to further evaluate findings from this study of low primate abundance and low hunting levels relative to the protected Korup National Park.

Ultimately, the results from this study indicate that widespread hunting levels may be associated with the presence of logging roads. Subsequently, the Ndokbou forest is not only exhibiting larger populations of primate species that are known to exploit hunted and degraded forests, but this forest is displaying overall low primate abundance even compared with a similar forest with greater hunting levels.

4.3 Passive Acoustic Monitoring as a Conservation Tool

An important methodological component of this study was the use of passive acoustic monitoring not only to assess gun-hunting levels, but also to monitor rare and cryptic primate species. Acoustic sensors successfully recorded 24 hrs/day through the entire duration of this

study with no loss of or damage to any sensor. When analyzing sound detections using the vocalization detector designed for Preuss's red colobus, vocalizations from every primate species encountered during forest surveys were recorded except for *P. preussi*. The absence of *P. preussi* vocalization detections could be representative of the low abundance of *P. preussi* in the forest, however, another factor could be that the preliminary form of the *P. preussi* detector used to scan acoustic files was not effective at detecting vocalizations of *P. preussi*.

The preliminary *P. preussi* detector used low quality recordings of *P. preussi* vocalizations as a basis for the algorithm to identify *P. preussi* vocalizations. Therefore, many vocalizations were identified using this detector, however, they were all false positive *P. preussi* vocalization detections. A next step would be to use the preliminary *P. preussi* detector on acoustic data from Korup National Park, where the largest population of *P. preussi* is found, and therefore the likelihood of detecting a true positive vocalization would be greater. True positive *P. preussi* vocalizations from those data could then be used to improve the preliminary detector algorithm to then re-run through the Ndokbou acoustic data with greater accuracy and likelihood of detecting *P. preussi* vocalizations. It would also be beneficial in the future to deploy an acoustic sensor in the Mt. Sinai region of the forest in grid 19 where the only *P. preussi* encounter occurred.

This is one limitation in the use of passive acoustic monitoring as a method for detecting rare and cryptic primate species: the detector used to identify species vocalizations is only as good as the vocalization recording used as the template for the detector algorithm. For example, male *C. nictitans*, *C. p. pogonias*, and *C. torquatus* vocalizations were frequently identified using the *P. preussi* detector because the males of these species have very distinctive loud calls that can be heard from long distances. *P. preussi* vocalizations are more difficult to detect most likely because of their high frequency (kHz) vocalizations that are not distinct and do not carry very far in dense rainforest habitats. Moreover, acoustic sensors can be effective for identifying the presence of primate species such as *M. leucophaeus*, *C. torquatus*, and *P. t. ellioti*, which have

distinct, low frequency, loud vocalizations. However, for species with more cryptic vocalizations, high quality recordings of their vocalizations are required and/or a larger, more dense grid of acoustic sensors are needed, particularly in rainforest regions in order to increase the likelihood of recording true positive vocalizations.

Acoustic sensor data successfully recorded the sounds of gunshots, and I was able to conduct analyses identifying temporal and geographic trends of gun hunting activity in the Ndokbou forest, which data from traditional forest surveys were unable to provide. Astaras *et al* (2017) also found important spatiotemporal patterns of gun hunting from passive acoustic monitoring methods suggesting that gun hunting occurs significantly more during the night, during weekdays leading up to market days, and during dry season months. Although the gunshot detector produced false positives which needed to be manually sorted and excluded from true positive detections, the use of acoustic sensors is clearly beneficial for identifying gun-hunting activity trends. For this study, I was limited to the use of six acoustic sensors, which did not cover the entire area surveyed for hunting signs. In the future it would be beneficial to ensure that acoustic sensors were covering the same area that forest surveys were conducted in order to make full area comparisons of gun hunting activity between these two methods. However, even considering some limitations and areas of improvement, passive acoustic monitoring methods provided an extremely more detailed understanding of gun hunting activities and patterns than forest survey methods. And ultimately, this novel use of passive acoustic monitoring has significant potential as an effective conservation tool used to improve the assessment of gun hunting activities in forests with wildlife species threatened by this human activity.

4.4 Conservation Outlook for the Ebo-Makombe-Ndokbou Forest Block

The Ebo-Makombe-Ndokbou forest block is an integral area in the Littoral region of Cameroon for overall biodiversity and specifically for rare and threatened primate populations (Morgan et al. 2011, 2013, 2020). Surveys conducted in the Ebo forest and results from this study

indicate that important populations of *P. t. ellioti*, *M. leucophaeus*, *C. torquatus*, *A. preussi*, and *P. preussi* are still present in these forests, even in the midst of wide-spread hunting and logging activities encountered in the Makombe and Ndokbou forests. My results suggest that within the Ndokbou forest, the Mt. Sinai region is most promising for retaining populations of rare and threatened primate species due to continued difficult human access for both hunting and logging activities. In addition, results from this study highlight concerns regarding the role that logging activities may be playing in exacerbating over-hunting in these forests by providing forest access through logging roads and bridges.

Therefore, conservation efforts should be focused on working with communities on developing post-logging mitigation plans that support the conservation of primate populations at risk from the synergistic impacts of hunting and logging activities. As previously mentioned, many logging bridges were destroyed in 2018, which does currently inhibit motorbike access to the interior of the Ndokbou forest. However, the intact logging bridge crossing the Grand Nouya river is providing continued walking access to the interior of the forest all year round. During a return trip from forest surveys, we were able to travel from the logging bridge crossing the Grand Nouya river north of grid 26 to the village of Ndokmen Nord within one day via the main logging road, whereas it took us four days to travel from Ndokmen Nord to Mt. Sinai using the natural topography of the forest with limited secondary logging roads and a natural crossing over Grand Nouya.

Results from this study indicate that the Mt. Sinai region of the Ndokbou forest may be one of the last remaining regions where both hunting and logging activities are limited and large-bodied primates are most abundant, including the only encountered group of *P. preussi* in this forest. Conservation efforts should also be focused on continued primate monitoring efforts within the region of grid 19 encompassing Mt. Sinai, grid 20, and regions east where the topography appears to be similar to Mt. Sinai and distances from the main logging road remain

far. The primate abundance results of this study should be a baseline used for future studies to further assess primate population abundance estimates.

In summary, results indicate that overall primate abundance is low within the Ndokbou forest compared with a protected forest with a similar primate community and greater levels of hunting. However, there are still important populations of threatened primate species in this forest that could benefit from directed conservation efforts. These efforts should focus on greater primate population monitoring and greater efforts to deter hunting activities by eliminating logging bridge access points. While hunting activity appears to be the most immediate threat to primates in this region, the presence of logging is also an area of concern for conservation.

Notable logging encounters during this study include cut stumps with none of the required number tracking imprints. Ten cut stumps encountered in grid 34 did not have the required numbers indicating the cut stump number, tree ID number, date cut, or the assiette de coupe number imprinted on the stumps. 8 of these trees were Azobe and 2 were Tali. The missing numbers were not a result of wood decay as the stumps were in the same condition as other stumps in the area with clear number imprints indicating cutting in 2017. My forest guide who had previously worked on logging operations in FMU 00-004 up until 2016 and knew the assiette de coupe boundaries well, indicated this was the result of trees being illegally cut outside of the official boundary, and therefore they received no official number imprint. The guide also indicated one loading area encountered in grid 34 was also located outside of the designated assiette de coupe boundary and this particular loading area was the only encounter with trees purposefully planted along the perimeter. While these claims cannot be officially verified, it highlights the fact that Azobe trees and Tali trees are being cut with no number imprints and therefore no tracking of the number cut or from where they are being cut. This is important not only for FSC certification purposes but also for the apparent lack of accountability for the extent to which Azobe tree species and Tali tree species – both of which are key species for the

Critically Endangered Preuss's red colobus - are actually being harvested out of the Ndokbou forest.

Broader implications of these findings related to hunting and logging activities found in the Ndokbou forest portray a grim outlook for the designation of a possible logging concession encompassing the entirety of the Ebo forest. In 2006 the Cameroon government made an official proposed designation of Ebo forest as a national park, as this forest contains key populations of *P. t. ellioti*, *M. leucophaeus*, and an as of yet undetermined subspecies of *G. gorilla*. However, the Cameroon government recently signed two decrees on February 4, 2020 proposing the conversion of the Ebo forest into two FMU logging concessions that will replace the entire Ebo forest (Morgan & Whytock, 2020).

Not only do results from this study show that logging activities may lead to increased levels of hunting, but audit reports from TRC logging operations between 2006 and 2012 in the Ndokbou forest repeatedly highlighted the need for greater restrictions of hunting activities occurring in the logging concession (Bureau Veritas Certification, 2012). As evidenced by the cutting of trees without proper tracking identification, the lack of accountability for logging companies adhering to rules even within the scope of FSC certification, is concerning. Moreover, the conversion of the Ebo forest into logging concessions could have compounding deleterious outcomes for the wildlife community and specifically primate populations already at risk from current levels of hunting including the Critically Endangered Preuss's red colobus.

Overall, the Ebo-Makombe-Ndokbou forests remain an important area for conservation with opportunities to improve the current state of primate abundance for the most at-risk species. But efforts are needed to continue monitoring Threatened primate populations with actions taken to reduce the continued impacts of logging operations including the dismantling of logging bridges and road access into forests. These forests still hold promising levels of biodiversity for the region, but it appears that if logging is left unrestricted with continued expansions, the future outlook for the regions' most Threatened species is uncertain.

Appendix

Appendix I. The total number (“nombre”) and volume (m³) of each tree species (“Essences”) inventoried by TRC for logging in FMU 00-004 of the Ndokou forest (Derived from Bureau Veritas Certification, 2012).

| Essences | nombre | volume | Essences | nombre | volume |
|----------------------|--------|--------|------------------|--------|--------|
| Abale | 57 | 378 | Eyoun blanc | 15 | 116 |
| Acajou blanc | 90 | 727 | Eyoun rouge | 41 | 38 |
| Agba | 2 | 24 | Faro | 177 | 1998 |
| Aiele / Abel | 176 | 1584 | Fraké / Limba | 333 | 2078 |
| Ako | 11 | 69 | Framiré | 2 | 7 |
| Alep | 613 | 4655 | Fromager / Ceiba | 76 | 902 |
| Angueuk | 131 | 939 | Iatandza | 4 | 33 |
| Asila | 5 | 27 | Ilomba | 906 | 5943 |
| Ayous | 2 | 15 | Iroko | 26 | 256 |
| Azobé | 3346 | 26527 | Kondroti | 2 | 16 |
| Bahia | 138 | 1112 | Kossipo | 44 | 471 |
| Bilinga | 505 | 4523 | Kotibé | 2 | 14 |
| Bodioa | 33 | 295 | Koto | 136 | 833 |
| Bongo H (Olon) | 131 | 869 | Koto | | |
| Bossé clair | 25 | 187 | Kumbi | 4 | 21 |
| Bossé foncé | 14 | 108 | Landa | 3 | 20 |
| Bubinga rose | 57 | 472 | Lati | 4 | 33 |
| Dabéma | 304 | 2845 | Limballi | 206 | 1930 |
| Dibetou | 13 | 128 | Lotofa | 4 | 25 |
| Doussie blanc | 5 | 42 | Makoré | 8 | 57 |
| Doussie rouge | 362 | 3010 | Mambodé | 199 | 1674 |
| Ebiara | 2 | 14 | Moabi | 9 | 95 |
| Ekop | 37 | 347 | Movingui | 114 | 792 |
| Ekop andinding | 3 | 22 | Mukulungu | 3 | 35 |
| Ekop G | 9 | 72 | Naga | 119 | 1093 |
| Ekop I | 2 | 17 | Niové | 31 | 235 |
| Ekop J | 9 | 67 | Oboto | 16 | 109 |
| Ekop M | 121 | 1061 | Okan | 191 | 1729 |
| Ekop Naga nord-ouest | 194 | 1706 | Onzabili K | 138 | 1071 |
| Ekop ngombé | 17 | 131 | Padouk rouge | 90 | 702 |
| Ekop ngombé mamelle | 4 | 42 | Sapelli | 13 | 140 |
| Ekop ribi | 15 | 117 | Sipo | 49 | 597 |
| Emien | 8 | 39 | Sougué | 109 | 857 |
| Esseang | 65 | 528 | Tali | 323 | 2783 |
| Eyek | 112 | 1209 | Tchitola | 12 | 108 |
| Eyong | 2 | 13 | Tiama | 14 | 116 |
| | | | Wenge | 1 | 9 |
| Total | 6620 | 53921 | | 0 | 3424 |
| Total général | | | | 10044 | 80857 |

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