

From forest to farmland: Effects of land use on understorey birds of Afrotropical rainforests

Dissertation

zur Erlangung des Doktorgrades

der Mathematisch-Naturwissenschaftlichen Fakultäten

der Georg-August-Universität zu Göttingen

vorgelegt von

M.Sc. Ing. Kadiri Serge BOBO

aus Kamerun

Göttingen 2007

D7

Referent: Prof. Dr. Michael Mühlenberg

Korreferent: Prof. Dr. Rainer Willmann

Tag der mündlichen Prüfung: 31.10.2007

PREFACE

After working on waterbirds in the Waza-Logone floodplain (1995-1998), I continued my interest in birds through involvement in field surveys to identify ‘Important Bird Areas’ of Cameroon as part of an African BirdLife International programme (1999-2000). I was introduced to the Korup area thanks to consultancy work offered by the WWF-CARPO in 2001 to elaboration on the ‘Wildlife Management Plan for the Nta-Ali Forest Reserve, extended by the GTZ-Cameroon on bird surveys of this same reserve. These experiences prepared me well for my Master of Science (2004) and the present PhD research.

The Korup area belongs to the Guineo-congolian rainforest zone; its flora is less degraded by humans and its vegetation cover is still impressive. Slash-and-burn agriculture is recurrent in the vicinity of villages. Land use systems are created by rural people searching for subsistence by clearing forest for farms. These habitats are home to a unique avifauna community, due to their strategic position at the most eastern limit of the Upper-guinean- and the western limit of the Lower-guinean- ecoregions. This created an exciting opportunity to contribute to the debate on birds in land use systems and to understand how environmental factors affect the entire avian community in our study area.

Development process of this thesis

Following a previous study which focused on the indicator properties of various taxa, namely birds through call-based methods, fruit-feeding butterflies, trees and understorey plants in the Korup area (see list of publications), the idea arose to further our understanding of the living conditions of bird communities in this area. The initial title “From forest to farmland: Effects of land use on birds of tropical rainforests” has been changed to “**From forest to farmland: Effects of land use on understorey birds of Afrotropical rainforests**” as we focused more on understorey birds in Cameroon, Central Africa. The presented works on ‘Understorey bird community structure, species richness and abundance’ (Chapter V.), ‘Ground and shrub nest predation risk, and availability of cavity nesting sites’ (Chapter VI.), ‘Food resources: Invertebrates, abundance and species richness of fruiting and flowering trees, and leaf litter area and weight’ (Chapter VII.) and other indicators of habitat quality like ‘Body weight,

ectoparasites, fault bars, fluctuating asymmetry' (Chapter VIII.) were developed together as systematic research, in the same temporal and spatial scales, using almost the same people. These have enabled us to discover some relationships and to interpret observed patterns in understorey birds (Chapter IX.).

Remarks on terminology

The present study has involved a large number of people with whom I worked in the field or as reviewers. Throughout this dissertation, "we" is used to stress common work and ideas.

Throughout this thesis, when comparing patterns along the gradient of forest disturbance, 'natural habitats' is used for near-primary forest and secondary forest habitats, and 'modified habitats' or 'land use systems' for agroforestry systems and annual cropfarms. The latter is also sometimes called 'annual cultures' or 'annual croplands'. Also, 'understorey birds' is referred to birds trapped with the mist-net; another synonym used is 'mist-netted bird community'.

Valid tree species names follow the Missouri Botanical Garden's VAST ([VAScular Tropicos](#)) nomenclatural database. Names of birds follow Borrow and Demey (2001). Invertebrate orders follow Steyskal *et al.* (1986).

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SUMMARY

Introduction

The effects of tropical forest disturbance and clearance on biodiversity have been investigated recently in several studies using species richness data from various taxonomic groups. However predictions of species extinction rates through habitat loss have been criticized partly because of the putative lack to acknowledge the potential value of agricultural production areas for the survival of tropical forest species. Recent studies have shown that a relatively high number of individuals and species can still be found in land use systems, species that form part of the natural forest fauna. Even if species richness changes little with disturbance, the trophic structure may alter and species characteristic of primary and old-growth secondary forest may be replaced by species associated with disturbed habitats. In the light of this, we intended (1) to extend our knowledge on patterns of species richness and abundance of understorey birds using mist-net data and (2) to assess some ecological correlates to detect key parameters for population development and pre-conditions for long-term suitability of different land use systems for forest bird populations.

The study took place in the North-eastern part of the Support Zone, outside Korup National Park, in the South West Province of Cameroon, at the centre of the Guinea Congolian forest refugium. We surveyed four habitat types with increasing human disturbance from near-primary forest, secondary forest, agroforestry systems constituted of cocoa/coffee plantations and annual croplands. Six sampling stations were selected in each of these habitats based on visual observations in the field to guarantee certain homogeneity of plots for a same habitat type. Topographically, all study sites were situated at approximately 250 m above sea level.

To fulfil our objectives, we firstly investigated understorey bird species richness, abundance and structure along our gradient of forest disturbance (Chapter V.). We then analysed the effects of this disturbance on bird nesting sites using artificial nests and searching for natural cavity nests (Chapter VI.). We also assessed the food for birds by looking at the availability of insects, fruiting and flowering trees along the same habitat gradient (Chapter VII). Moreover we checked some bird ecological correlates such as body weight, ectoparasites, fault bars, fluctuating asymmetry, adult territory owners, and specifically the effects of leaf litter area

and weight on ground foraging birds (Chapter VIII.). A synthesis and concluding remarks are presented in Chapter IX.

Understorey bird community structure, species richness and abundance

In chapter V., we discussed the effects of habitat types on diversity and abundance of understorey birds. Although the overall abundance (number of individuals) did not differ significantly between habitat types, it seemed to show an increasing pattern with increasing habitat modification. Overall species richness showed an increasing pattern with increasing habitat modification. Different bird groups/guilds responded in different ways. Species similarity was higher among natural habitats than among land use sites, and low between natural habitats and land use systems. Among our four habitat types, just the abundance of the mist-netted bird community from agroforestry systems that differed significantly from a lognormal distribution and fitted to the logseries distribution. Species with restricted geographic range, and with large body mass, have shown a preference for near-primary forest; species normally foraging at canopy level shifted in the understorey in annual croplands. While, captures of insectivores were significantly higher in natural habitats than in land use systems, granivores, omnivores and to some extent frugivores showed the opposite. We suspected the number of recaptures of insectivores to be higher in natural habitats than in land use systems as captures and individuals along the habitat gradient showed opposite trends. Mist-netting data presented different species richness patterns, a much higher species turnover and a much lower habitat specificity than the call-based method data.

Nest predation risk and availability of cavity nesting sites

In Chapter VI., we investigated the reproductive success of forest birds along our gradient of forest disturbance, using ground and shrub artificial nests baited with ‘country’ fowl eggs. This was completed with the assessment of the availability of cavity nesting sites. A low predation rate of 20% was found, meaning a relatively high reproductive success. Habitat types did not show any effect neither on overall nests, nor on ground or on shrub nets, but predation rate from ground nests was significantly higher than that from shrub nests. Rat, squirrel and snakes have been identified as the most common egg predators. Neither overall predator indices, nor from ground or from shrub nests were significantly different between habitat types, but the amount of indices from ground nests was significantly higher than those

from shrub nests. No significant correlation was found between vegetation parameters and artificial nest type intensities. Bird nesting cavities showed a clear increasing pattern with increasing habitat modification. Owls, Hornbills and Trogons were found using trees mostly from natural habitats, but almost all tree species in all habitat types were used the same way by birds to dig their nesting cavities.

Food availability for birds, leaf-litter area and weight

In Chapter VII., we assessed the availability of invertebrates, fruiting and flowering trees as food resources for birds, and we investigated the influence of leaf-litter area and weight on ground foraging birds. Invertebrates order richness, abundance and average length increased significantly from natural to modified habitats. Although similarity between sites is high, the four habitat types differed in invertebrate orders composition, the difference being smaller among annual crop sites. Fourteen of the 28 invertebrate orders recorded showed significant responses to habitat types. Although no clearly defined patterns were observed in flowering and fruiting tree species richness and density, near-primary forest showed significantly lower values as compared to other habitat types. Two flowering and five fruiting tree species known to invade degraded habitats were found to be the most attractive for many bird families during the sampling period. Overall invertebrate abundance was strongly negatively correlated with ant-following bird species richness and abundance. All significant correlations found between the fruiting and flowering trees, and the studied bird groups/guilds were moderate and positive. The higher abundance of invertebrates, flowering and fruiting trees in our land use systems might largely explain, at least temporally, the occurrence of some understorey forest birds in modified habitats. While the relationships between the leaf-litter area and the respective ground foraging bird groups studied were all positive and insignificant, the leaf-litter weight was positively and significantly correlated with all the studied ground foraging bird parameters, meaning that larger leaves on the secondary forest floor did not negatively affect the foraging ability of terrestrial insectivorous birds.

Ectoparasites, fault bars, fluctuating asymmetry, body weight and adult territory owners

In Chapter VIII., we argued on indicators of habitat quality that influence birds directly or indirectly. Average body weight across species showed a significantly decreasing pattern with

increasing habitat modification, confirming our earlier findings on body mass and habitat preference (see Chapter V.). Although habitat types did not significantly affect the number and the proportion of bird individuals and species infested with ectoparasites, natural habitats showed higher values than land use habitats. The number and the proportion of bird species and individuals presenting fault bars, showed a significantly increasing pattern with increasing habitat modification. Fluctuating asymmetry patterns seemed to increase with increasing habitat modification, with more evidence on tarsi and/or wings of Little Greenbul, Yellow-whiskered Greenbul and Olive Sunbird; no evidence appeared for insectivorous birds. Although, the number and the proportion of overall adult territory owners, were not significantly affected by habitat types, near-primary forest showed the lowest recaptured individuals and recapture rates, meaning that territories in this habitat type are larger than those in land use systems. But, adult territory insectivore owners were more abundant in natural habitats than in modified habitats.

Implications for conservation

To better conserve Afro-tropical rainforest birds in the agricultural matrix, the proximity of primary forest matters greatly. Between 15 and 20% of the original basal area and forest tree species, and dead trees should be left. Clear cutting of large areas and mono-specific plantations (e.g. palm trees, bananas, cocoa/coffee, ...) should be avoided as much as possible. Three to five years of fallow is also essential in order to create temporal favourable microclimate conditions suitable to attract many forest bird species. Efforts should also be made to keep poaching to a minimum and to provide alternative sources of protein and income to bushmeat. Additionally, efforts should be made to minimise the phenomenon of using bird parts for cultural and traditional purposes, and to stop the observed trade of bird parts between Nigerians and local hunters. We should try as much as possible to sustainably manage land use systems, particularly logging areas, in order to avoid their expansion while continuing to satisfy increasing human needs.

Synthesis

Food availability might have played a great role in attracting understorey birds in modified habitats. Consequently, higher intra and interspecific competition certainly exists in these habitat types for space and food. This has had negative effects in reducing bird weight and

territory size. Land use systems, which are closer to natural habitats in our study area, also contributed in infesting forest birds with ectoparasites during the time spent outside their normal territories looking for food, thus explaining why many forest bird species were captured there, especially insectivores. This great flux between habitat types also explained the observed patterns of fluctuating asymmetry. But, fluctuating asymmetry in tarsi and/or wings of species like Olive Sunbird, Yellow-whiskered Greenbul and Little Greenbul, fault bars, cavity nesting sites for Owls, Trogons and Hornbills, and the number of adult territory owners of insectivores could be used as indicators for habitat quality. The reproductive success of birds seemed to be considerable in our study area. Therefore we expect fewer nesting attempts each breeding season, and higher clutch size. This should be considered for further research. The observed patterns described in this thesis might also vary according to seasons; thus a comparative study during the main rainy season is essential before drawing any definitive conclusion. In the Afro-tropical context, biological, socio-economic (including local livelihood issues) and cultural aspects should be investigated simultaneously in order to understand how they are related. Most importantly, the management of land use systems should consider preserving nearby natural habitats to avoid biodiversity loss.

ZUSAMMENFASSUNG

Einleitung

Die Auswirkungen der Veränderung und Rodung tropischer Wälder auf die Biodiversität wurde in jüngerer Zeit in verschiedenen Studien zur Artenvielfalt veränderter Habitate untersucht. Vorhersagen durch Habitatverluste bedingter Aussterberaten geraten jedoch teilweise unter Kritik wegen des vermeintlichen Wissensdefizits um das Lebensraumpotenzial landwirtschaftlicher Produktionsflächen auch für die Arten tropischer Wälder. Kürzlich haben verschiedene Studien gezeigt, dass eine verhältnismäßig hohe Anzahl von Arten, darunter auch Arten der Naturwaldfauna, auch in Landnutzungssystemen angetroffen werden können. Doch auch wenn sich die durchschnittliche Artenvielfalt mit zunehmender Habitatveränderung wenig ändert, können sich die trophischen Strukturen und der Anteil der für sekundäre Lebensräume typischen Arten in den Artengemeinschaften verändern. Vor diesem Hintergrund war es Ziel dieser Studie Muster der Artenvielfalt und Abundanzen von Unterholzvögeln zu untersuchen. Um die langfristige Eignung von Landnutzungssystemen als Lebensraum für Waldvogelarten zu ermitteln wurden Abundanzen und biometrische Daten von mit Japannetzen gefangenen Vögeln sowie ökologische Parameter erhoben.

Die Studie wurde durchgeführt im nordöstlichen Bereich der Pufferzone des Korup Nationalparks im Südwesten Kameruns. Im Untersuchungsgebiet wurden vier Habitattypen mit zunehmender anthropogener Veränderung der ursprünglichen Wälder abgegrenzt: wenig gestörte Primärwald, Sekundärwald, Agroforstsysteme mit Kakao/Kaffee-Plantagen und annuelle Kulturen. Sechs Untersuchungsflächen wurden in jedem dieser Habitattypen derart ausgewählt, dass eine gewisse Homogenität der Flächen im jeweiligen Habitattyp gegeben war. Alle Untersuchungsflächen lagen auf etwa 250 m üNN.

Zunächst wurden Artenreichtum, Abundanzen und Strukturen der Artengemeinschaften entlang eines Gradienten zunehmender Habitatveränderung untersucht (Abschnitt V.). Anschließend wurde mittels Kunstnestern und der Suche nach Bruthöhlen der Einfluss auf die Nistplatzwahl untersucht (Abschnitt VI.). Weiterhin wurde die Nahrungsbasis für Vögel in den unterschiedlichen Habitattypen anhand der Verfügbarkeit von Insekten sowie blühenden und fruchtenden Bäumen ermittelt (Abschnitt VII.). Weitere Parameter wie Gewicht, Vorhandensein von Ektoparasiten, Hungerstreifen und variabler Asymmetrie sowie die

Anzahl adulter Revierinhaber und die Effekte von Blattstreufäche und –gewicht wurden analysiert um die Habitatqualitäten im ökologischen Kontext zu beurteilen (Abschnitt VIII.). Eine Synthese der Ergebnisse und Schlussfolgerungen werden in Abschnitt IX. dargestellt.

Struktur, Artenvielfalt und Abundanzen der Artengemeinschaften von Unterholzvögeln

In Abschnitt V. wurden die Auswirkungen der Habitatveränderung auf die Abundanzen und Diversität von Unterholzvögeln dargestellt. Obwohl die durchschnittliche Abundanz (Anzahl von Individuen) zwischen den Habitattypen nicht signifikant unterschiedlich war, ergab sich tendenzielle eine Zunahme mit zunehmender Veränderung. Die durchschnittliche Artenvielfalt nahm in gleicher Weise tendenziell zu. Die Reaktion fiel je nach betrachteter Gruppe/Gilde unterschiedlich aus. Die Similarität der Artenzusammensetzung war zwischen den natürlichen Habitaten höher als zwischen den Landnutzungstypen und gering zwischen Naturwald und Landnutzungstypen. Unter den vier Habitattypen zeigte sich nur für die Artengemeinschaft der Agroforstflächen ein signifikanter Unterschied von einer lognormal und eine Ähnlichkeit zu einer logseries Verteilung. Arten mit begrenztem geografischen Verbreitungsgebiet und solche mit großer Körpermasse zeigten eine stärkere Bindung an den wenig veränderten Primärwald. Arten, welche eigentlich im Kronenraum Nahrung suchen, waren in den annuellen Kulturen im Unterholzbereich aktiv. Während die Fangraten von insektivoren Arten im Primärwald signifikant höher waren als in den Landnutzungstypen, zeigte sich für granivore, omnivore und tlw. auch für frugivore Arten das Gegenteil. Anhand der Netzfangraten zeigten sich andere Muster der Artenvielfalt, eine wesentliche höhere Fluktuation und wesentlich geringere Habitatunterschiede als anhand der auf Lautäußerung basierenden Erhebungen.

Nestprädatonsrisiko und Höhlenbrüter

In Abschnitt VI. wurden die Erhebungen zum Reproduktionserfolg von Waldvögeln entlang des Störungsgradienten dargestellt. Künstliche Boden- und Strauchnester wurden dazu mit Hühnereiern beködert. Ergänzend wurde Erhebungen zu Nisthöhlen gemacht. Es wurde eine geringe Prädatonsrate von 20 % festgestellt, was einem relativ hohen Bruterfolg gleichzusetzen wäre. Es ergaben sich zwischen den Habitattypen weder Unterschiede im Gesamtdurchschnitt der Prädatonsraten noch im jeweiligen Vergleich der Boden- oder

Strauchnester. Die Prädationsrate bei den Bodennestern war jedoch signifikant höher als bei Strauchnestern. Ratten, Hörnchen und Schlangen wurden als die häufigsten Nestprädatoren identifiziert. Weder die gesamt durchschnittlichen Prädatorenindizes noch die nach Boden- und Strauchnestern waren zwischen den Habitattypen signifikant unterschiedlich. Wiederum ergaben sich aber signifikant höherer Werte für Bodennester im Vergleich zu Strauchnestern. Vegetationsparameter zeigten keine signifikante Korrelation mit der Intensität der Prädation an Kunstnestern. Bruthöhlen nahmen mit zunehmender Habitatveränderung zu. Eulen, Hornvögel und Trogons nutzten zumeist Bäumen in Naturwaldhabitaten aber fast alle Baumarten wurden in allen Habitaten in der gleichen Weise zur Nisthöhlenanlage genutzt.

Nahrungsverfügbarkeit für Vögel, Blattstreufläche und- gewicht

In Abschnitt VII. werden die Verfügbarkeit von Invertebraten, Fruchtbäumen und blühenden Bäumen als Nahrungsressourcen für Vögel entlang des Störungsgradienten dargestellt. Die Vielfalt an Insektenordnungen, Abundanz und durchschnittliche Länge nahmen entlang des Gradienten vom Naturwald zu den veränderten Habitaten signifikant zu. Obwohl die Similarität zwischen den Untersuchungsflächen generell hoch war, unterschied sich die Zusammensetzung nach Insektenordnungen zwischen den Habitattypen mit geringeren Unterschieden in den annuellen Feldkulturen. 14 der 28 erfassten Insektenordnungen zeigten signifikante Reaktionen auf die Habitatveränderung. Was die Vielfalt und Dichte der Fruchtbäume und blühenden Bäume angeht, zeigte sich kein klares Muster aber im Naturwald waren die Werte am niedrigsten. Zwei Arten blühender und fünf Fruchtb Baumarten, die in gestörte Habitate einwandern, erwiesen sich als die attraktivsten für viele Vogelfamilien im Beobachtungszeitraum. Die durchschnittliche Abundanz von Invertebraten war stark negativ korreliert mit der Vielfalt und Abundanz von Ameisenvögeln und mittelgroße blattabsammelnden Vogelarten. Alle signifikanten Zusammenhänge zwischen den Werten für Frucht- und blühende Bäume waren moderat und positiv. Die höhere Abundanz von Invertebraten und diesen beiden Baumartengruppen in den Landnutzungssystemen könnte erklären, warum Unterholzvögel zumindest vorübergehend auch in veränderten Habitaten überdauern können. Während die Beziehung zwischen Blattstreufläche und den diesbezüglich untersuchten bodenabsuchenden Vogelarten alle positiv und nicht signifikant waren, war das Gewicht der Blattstreu positiv und signifikant korreliert mit allen untersuchten Parametern bodenabsuchender Vogelarten. Das bedeutet, dass größere Blätter auf dem Boden des

Sekundärwalds keinen negativen Einfluss auf den Artenreichtum und die Abundanz dieser Vogelartengruppe hatten.

Parasiten, Hungerstreifen, variable Asymmetrie, Körpermasse und adulte Revierinhaber

In Abschnitt VIII. wurde der direkte und indirekte Einfluss anderer Faktoren auf die Vogelwelt entlang des Störungsgradienten untersucht. Insgesamt nahm die durchschnittliche Körpermasse von Unterholzvögeln mit zunehmender Habitatveränderung signifikant ab, was vorherige Ergebnisse über Körpermasse und Habitatpräferenz bestätigt (siehe Abschnitt V.). Obwohl Habitattypen keinen signifikanten Einfluss auf die Individuenzahlen und Arten mit Ektoparasiten und deren Anteil hatten, zeigt sich höhere Werte im Naturwald als in Landnutzungssystemen. Vogelarten und Individuen mit Hungerstreifen, ebenso wie ihr Anteil, nahmen mit zunehmender Habitatveränderung signifikant zu. Variable Asymmetrie schien mit zunehmender Habitatveränderung zuzunehmen. Deutlicher wurde dies bei Tarsus und/oder Flügelmaßen von Little Greenbul, Yellow-whiskered Greenbul und Olive Sunbird. Bei insektivoren Arten ergab sich keine Evidenz. Obwohl die Anzahl aller adulten Revierinhaber ebenso wie deren Anteil nicht signifikant von Habitattypen abhing, waren die Zahlen im Naturwald am geringsten. Das bedeutet, dass die Revier in diesem Habitattyp größer waren als in den Landnutzungssystemen. Dagegen war die Anzahl solcher Individuen bei den insektivoren Arten im Naturwald höher als in den veränderten Habitaten.

Schlussfolgerungen für den Naturschutz

Zum besseren Schutz afrotropischer Vogelarten in einer landwirtschaftlichen Landschaftsmatrix ist die Nähe zu Primärwald von besonderer Bedeutung. Zwischen 15 und 20 % der ursprünglichen Bestandesgrundfläche und der Baumarten sollten ebenso wie Totholz erhalten bleiben. Großflächige Kahlschläge und monospezifische Plantagen (z.B. Palmen, Bananen, Kakao/Kaffe, ...) sollten soweit wie möglich vermieden werden. Drei- bis fünfjährige Brachestadien sind ebenso wesentlich um temporäre mikroklimatische Bedingungen zu schaffen, welche viele Waldvogelarten anziehen können. Ebenso sollte Wilderei eingedämmt werden und Alternativen der Proteinversorgung und Einkommensgenerierung entwickelt werden. Die Nutzung von Vogelkörperteilen für

kulturelle und traditionelle Zwecke sollte minimiert und der beobachtete Handel mit Vögeln zwischen Nigerianern und lokalen Jägern unterbunden werden. Ebenso sollte das Management von Landnutzungssystemen, insbesondere Holzeinschlagsflächen, verbessert werden um deren weitere Ausdehnung zu verhindern und gleichzeitig die wachsenden Bedürfnisse der Bevölkerung zu befriedigen.

Synthese

Die Nahrungsverfügbarkeit mag eine große Rolle dabei gespielt haben, dass Unterholzvögeln auch in veränderten Habitaten zu finden waren. Entsprechend existiert sicher eine höhere intra- und interspezifische Konkurrenz um Raum und Nahrung in diesen Habitattypen. Dieses hatte negative Effekte auf die Größe der Reviere und das Körpergewicht. Durch die größere Nähe zum Naturwald waren Vögel aus Landnutzungssystemen, die auf der Nahrungssuche auch außerhalb ihrer Territorien umherstreifen mehr mit Ektoparasiten befallen. Dies erklärt auch warum dort viele Waldvögel, insbesondere insektivore, in den Netzen gefangen wurden. Dieser große Fluss zwischen den Habitattypen erklärt auch die beobachteten Muster der variablen Asymmetrie. Dennoch können variable Asymmetrie (Tarsus- und Flügelmaße) bei einigen Arten, Hungerstreifen, Bruthöhlen für Eulen, Trogons und Hornvögel und die Anzahl adulter Revierinhaber als Indikatoren für die Beurteilung der Habitatqualität für Vögel herangezogen werden. Der Reproduktionserfolg im Untersuchungsgebiet erschien bemerkenswert. Folglich kann man eine geringere Zahl von Brutversuchen je Brutsaison erwarten, welches zu größeren Gelegen führt. Dieses sollte bei weiteren Untersuchungen an Vögeln in diesem Gebiet berücksichtigt werden. Die hier dargestellten Muster könnten ebenso jahreszeitlich unterschiedlich sein. Eine vergleichende Studie in der Hauptregenzeit wäre erforderlich bevor endgültige Schlüsse gezogen werden können. Im afrotropischen Kontext sollten biologische, sozioökonomische und kulturelle Aspekte simultan untersucht werden um das Beziehungsgefüge besser zu verstehen. Insbesondere beim Management von Landnutzungssystemen sollte die Erhaltung von Merkmalen natürlicher Lebensräume zur Bewahrung der Biodiversität im Kontext mit den Bedürfnissen der lokalen Bevölkerung erfolgen.

GENERAL INTRODUCTION

- I. Background
- II. Status of current research
- III. Importance, Objectives and Hypotheses
- IV. The study area

I

BACKGROUND

I.1. Notes on the Guinea-Congolian rainforest avifauna

The Guinea-Congolian rainforest contains some 280 bird species that are restricted to this biome of which 15 are endemic to the Upper Guinean Area (EBA 084), six to the Cameroon and Gabon lowlands (EBA 085) and 29 to the Cameroon mountains (EBA 086) (Fishpool & Evans 2001).

These figures of species richness and endemism of the Guinea-Congolian rainforest area are low when comparing with similar-sized tropical lowland forest areas (Keast 1990, Stattersfield *et al.* 1998). This low level of endemism is generally accompanied by a low habitat specialisation known to be *c.* 9% in the Afrotropics against *c.* 40 % in the Neotropics, 50% in the Indo-Malayan and 25% in the Australian region (see Keast 1990). This low β -diversity in African forests seems to be accompanied by a low α -diversity (see Karr 1976). There also seem to be fewer specialisations in food and foraging techniques in Africa than in the Neotropics (Karr 1976). Range and diversity of body sizes seems to be higher as well in the Neotropics (Karr 1976). The generally low generic and familial diversity and relatively high taxonomical richness of groups such as phasianids, kingfishers, barbets and the paucity of parrots and trogons are other characteristics of African rainforests (Karr 1976). Species richness in a given habitat is considered being more related to ecological factors such as current vegetation productivity (Waide *et al.* 1999) and habitat complexity (Fjeldså 1997).

I.2. Notes on the avifauna of Cameroon

Cameroon is a very rich country in terms of biodiversity, with a large variety of biogeographical units and habitats, due to its position in the Gulf of Guinea, between West and Central Africa, between the Atlantic Ocean and Lake Chad, and at the edge of the Sahel belt. This richness in landscapes and biodiversity is of course also increased by the presence of the Western Cameroon Mountains.

The Cameroon avifauna is particularly rich and the country now harbours 927 confirmed species (see Languy *et al.* 2005, Bobo *et al.* 2007) of which seven are endemic to Cameroon (Fishpool & Evans 2001); 29 restricted-range species is known to occurs in the Cameroon mountains (Endemic Bird Area No. 086) and six in the Cameroon and Gabon lowlands (Endemic Bird Area No. 085) (Borrow & Demey 2001); one of the Cameroon endemics is confined to the Bamenda Highlands and the Adamawa Plateau (Bobo *et al.* 2001). Cameroon is divided into four biomes to which also certain species are restricted to: ten species are confined to the Sahel biome, 45 species to the Sudan-Guinea Savanna biome, 215 species to the Guinea-Congo Forests biome and 44 species to the Afrotropical Highlands biome (Fishpool & Evans 2001). Many bird species will still have to be confirmed and many others need to be discovered, as some areas have never been surveyed.

To better conserve this rich avifauna, as well as their habitats and many other elements of biodiversity at ecosystem, taxon and genome level, Cameroon has recently embarked in a BirdLife International-Africa programme seeking to promote the conservation of biodiversity based on a network of selected sites called Important Bird Areas (Fishpool & Evans 2001) as birds are one of the best-researched and most reliable indicators of terrestrial biological richness and environmental conditions in the world (Bibby 1999). Nonetheless many of these areas, although parts of the protected areas network of the country, are facing various threats.

I.3. Threats to Cameroon avifauna

Main threats to the Cameroonian avifauna are:

- Agricultural encroachment including fire, habitat clearance for agriculture, grazing, firewood collection;
- Over-exploitation including poaching of birds and other wildlife, extraction of fuelwood and timber, overgrazing;
- Negative impacts of tourism, excessive erosion, mining and pollution.

I.4. Species of global conservation concern in Cameroon

Forty-one species of global conservation concern are known from Cameroon (BirdLife International 2004):

- Six, all resident birds, are known to be Endangered (EN) of which five are montane forest species namely the Mount Cameroon Francolin *Francolinus camerunensis*, Bannerman's Turaco *Tauraco bannermani*, Mount Kupe Bush-shrike *Malaconotus kupeensis*, White-throated Mountain-babbler *Kupeornis gilberti*, Banded Wattle-eye *Platysteira laticincta* and one, the Bates's Weaver *Ploceus batesi* is a lowland forest species;
- Six are known to be Vulnerable (VU) of which four, the Green-breasted Bush-shrike *Malaconotus gladiator*, Grey-necked Picathartes *Picathartes oreas*, Mount Cameroon Speirops *Speirops melanocephalus* and Bannerman's Weaver *Ploceus bannermani* are Resident birds and are found in montane forests, one, the Lappet-faced Vulture *Torgos tracheliotus* is Resident to the Sahel belt, and the Cape Gannet *Morus capensis* is a scarce non-breeding visitor from South African waters to Gulf of Guinea (Borrow and Demey (2001);
- Twenty are known to be Near-Threatened (NT) of which three are Palearctic migrants (Ferruginous Duck *Aythya nyroca*, Pallid Harrier *Circus macrourus*, Great Snipe *Gallinago media*), five are rare Residents to Partial/Intra-African migrants (Lesser Flamingo *Phoenicopterus minor*, Damara Tern *Sterna balaenarum*, African Skimmer *Rynchops flavirostris*, Black Crowned-crane *Baeurica pavonina*, Stanley's Bustard *Neotis denhami*), five are lowland forest Residents (Hartlaub's Duck *Pteronetta hartlaubii*, Shelley's Eagle-owl *Bubo shelleyi*, Yellow-casqued Hornbill *Ceratogymna elata*, Dja River Warbler *Bradypterus grandis*, Gabon Batis *Batis minima*), and seven are montane to sub-montane forest Residents (Bangwa Forest Warbler *Bradypterus bangwaensis*, White-naped Pigeon *Columba albinucha*, Cameroon Greenbul *Andropadus montanus*, White-tailed Warbler *Poliolais lopezi*, Crossley's Ground-thrush *Zoothera crossleyi*, Ursula's Sunbird *Nectarinia ursulae*, Grey-headed Greenbul *Phyllastrephus poliocephalus*);
- Nine are known to be Data Deficient (DD) of which one is a rare to locally uncommon Palearctic migrant (Black-winged Pratincole *Glareola nordmanni*), five are lowland forest Residents (White-crested Bittern *Tigriornis leucolophus*, Yellow-footed Honeyguide *Melignomon eisentrauti*, Eastern Wattled Cuckoo-shrike *Campephaga oriolina*, Sangha Forest Robin *Stiphornis erythrothorax sanghensis*, Tessmann's Flycatcher *Muscicapa tessmanni*), two are montane/highland forest Residents

(Monteiro's Bush-shrike *Malaconotus monteiri*, Fernando Po Swift *Apus sladeniae*)
and one is a savanna Resident (Dorst's Cisticola *Cisticola dorsti*).

II

STATUS OF CURRENT RESEARCH

II.1. Land use and biodiversity change in tropical forests

Deforestation in the humid tropics is one of the major threats to global biodiversity (Dobson *et al.* 1997, Park 1992). The combination of rapid land use change and high diversity in the tropics has made these areas particularly vulnerable to species loss (Brooks *et al.* 2002, Chapin *et al.* 2000). The effects of tropical forest disturbance and clearance on biodiversity have been investigated recently in several studies using species richness data from various taxonomic groups. Generally, species richness declines with increasing habitat modification investigated for invertebrates (Lawton *et al.* 1998, Stork *et al.* 2003), birds (Lawton *et al.* 1998, Waltert *et al.* 2004a, Bobo 2004, Waltert *et al.* 2005), ungulates (Fritz *et al.* 2003), carnivores (Cuaron *et al.* 2004), primates (Chapman & Lambert 2000, Waltert *et al.* 2002). Predictions of species extinction rates from habitat loss in the tropics have been made several times (Reid 1992, Brooks *et al.* 2002, Waltert *et al.* 2004b), but have been criticized partly because of the putative lack to acknowledge the potential value of agricultural production areas for the survival of tropical forest species (Pimentel *et al.* 1992, Budiansky 1994, Poudevigne & Baudry 2003).

Recently, several studies showed that a relatively high number of individuals and species can still be found in land use systems, species that form part of the natural forest fauna (Estrada *et al.* 1993, Merker & Mühlenberg 2000, Daily *et al.* 2001). However, abundances may also be affected by interspecific interactions, as suggested in models of density compensation (MacArthur *et al.* 1972). Even if richness changes little with disturbance, the trophic structure may alter and species characteristic of primary and old-growth secondary forest may be replaced by species associated with disturbed habitats (e.g. Marshall & Swaine 1992, Estrada *et al.* 1994, Lindell & Smith 2003). In general, anthropogenically altered habitats might reduce the density of rare and habitat specialist species while favouring habitat generalists (Malcolm 1997, Meffe & Carroll 1997, Horváth *et al.* 2001, Sampaio *et al.* 2003).

However, a cautious interpretation of abundance and species richness data is necessary since deforestation in many parts of the tropics is a relatively recent phenomenon, intensification of the agricultural land is still ongoing and so far only little information on the long-term stability of faunal populations in land use systems is available (Donald 2004). In order to increase our understanding of how disturbed ecosystems and communities are structured, it is necessary to obtain information on species richness and distribution patterns in intact rainforest (Boulinier *et al.* 1998, Wilson 1988) and to examine responses of tropical species and ecosystems to landscape modification (Estrada *et al.* 1993, Johns 1992, Lugo 1988). This leads to more efficient designs for reserves and to strategies for maintaining biological diversity and natural ecosystem integrity in human-dominated ecosystems (see also Fjeldsa *et al.* 2004).

II.2. Birds and land-use systems

Studies on birds in tropical agro-ecosystems revealed that traditional agro-forests, with a mix of cultivated and natural shade trees, can support a high number of species, including many forest specialists, especially in close proximity of natural forest (Thiollay 1995, Greenberg *et al.* 1997b). In contrast, agro-forests with planted shade trees, even if composed of many tree species, only support but few forest specialist birds in the absence of nearby primary forest (Greenberg *et al.* 1997a, Greenberg *et al.* 2000). Annual cultures generally do not support high numbers of bird species in forest regions, but the picture can be different if groups of tall trees and forest fragments are left in the agricultural landscape (Daily *et al.* 2001, Hughes *et al.* 2002).

Large size (Thiollay 1995), understorey dwelling rather than canopy or edge dwelling habit (Terborgh & Weske 1969, Andrade & Rubio-Torgler 1994, Thiollay 1995, Petit & Petit 2003), being insectivorous (Bowman *et al.* 1990, Johns 1991, Thiollay 1995, Canaday 1996, Plumptre 1997, Raman *et al.* 1998, Waltert *et al.* 2004a), having specialised foraging strategies (Terborgh & Weske 1969, Lindell & Smith 2003), and having a restricted geographic range (Raman 2001, Waltert *et al.* 2004a) are characteristics that make forest species sensitive to deforestation and land use. In addition, it has been suggested that resident habits – in contrast to being a non-breeding visitor – is particularly linked to preference of forest habitats (Lindell *et al.* 2004), and that resident forest species often are behaviourally inhibited to enter open agricultural land seeing them as a barrier for dispersal (Harris & Reed 2002).

Most information on bird species richness in tropical land use systems is available from America (Estrada *et al.* 1997, Greenberg *et al.* 1997a, Greenberg *et al.* 1997b, Petit *et al.* 1999, Daily *et al.* 2001, Hughes *et al.* 2002), only few detailed studies exist from Africa (see Elgood & Sibley 1964, Blankespoor 1991, Kofron & Chapman 1995, Plumptre 1997, Lawton *et al.* 1998, Bobo 2004, Waltert *et al.* 2005), South/Southeast Asia (Beehler *et al.* 1987, Thiollay 1995) or Australasia (Bowman *et al.* 1990, Alvard & Winarni 1999, Poulsen & Lambert 2000, Waltert *et al.* 2004).

In Cameroon, Lawton *et al.* (1998) in Mbalmayo documented a significant decrease in overall bird species richness from forest to plantations. Bobo (2004) and Waltert *et al.* (2005) in the Korup region rather showed that overall bird species richness can also remain fairly constant between habitat types, but that species richness of certain groups such as insectivores (large arboreal foliage gleaners, terrestrial insectivores and ant-followers), pycnonotids (insectivores/insectivores-omnivores) and biome-restricted species (i.e. species that are confined to the Guineo-Congolian forest zone) are adversely affected by forest modification and land use. Tree density and basal area have been found being positively correlated with species richness of insectivores, especially terrestrial insectivores, large- and medium-sized foliage gleaners, as well as with species richness of ant followers, the group of range-restricted species, and the Pycnonotidae family, while these vegetation parameters are negatively correlated with species richness of flower-visiting species, and non-breeding migrants (Bobo 2004, Waltert *et al.* 2005). This dependency of a large number of forest biome species on trees is self-evident and can explain the low farmland bird diversity in technified production systems (Lawton *et al.* 1998, Waltert *et al.* 2004a).

In order to improve our understanding of the potential role of land use systems for different groups of birds (categorised by ecology, taxonomic affinities, and geographic range), further research on population development (monitoring), and detailed analyses of certain habitat features (food resources, nesting sites, biotic interactions) in different habitat types is essential (Donald 2004).

II.3. Knowledge on biodiversity in land use systems from our study area

Birds, fruit feeding butterflies, trees and understorey plants diversity and abundance have already been explored separately:

- Species richness patterns of trees and understorey plants along a gradient of forest conversion (Bobo *et al.* 2006a).
- Butterfly diversity and habitat associations along a gradient of forest conversion (Bobo *et al.* 2006b).
- Habitat effects on afrotropical forest bird diversity (Waltert *et al.* 2005).

III

IMPORTANCE, OBJECTIVES AND HYPOTHESES

III.1. Importance

As resources and time for the conservation of biodiversity are limited, indicator groups of overall species richness may represent a useful and rapid method for assessing biodiversity (Hughes *et al.* 2000, Schulze *et al.* 2004, Kremen *et al.* 2003, Lawton *et al.* 1998). In this sense, we aim to embed our study into a larger assessment of biodiversity in tropical land use systems, where also arthropods, trees and other plants are included, so that statements about the influence of land use on the ecosystem in a wider sense will be possible, and an increased understanding of differences in abundance and diversity patterns of phylogenetically unrelated groups is achieved.

Here, an emphasis is put on the investigation of diversity and abundance patterns of understorey birds along a gradient of land use systems, and the responsible underlying ecological factors. It becomes important to broaden the understanding of the effects of human impact on different taxa, ecological guilds, and geographic ranges. The question of this project is not how to preserve nature in its original state, but by identifying key parameters, to help improve biodiversity conservation in human-dominated tropical landscapes (Rosenzweig 2003).

III.2. Objectives

Since the patterns of species richness and abundance of birds along a gradient of human disturbance in near-primary forest (NF), *ca.* 15 years old-secondary forest (SF), agroforestry systems (AF) and annual cultures (AC) using the call-based method are already well – documented (Bobo 2004, Waltert *et al.* 2005), with this study we intend to extend our knowledge on patterns of species richness and abundance of understorey birds using mist-net data and the value of tropical land use systems for birds having the following objectives:

- To document patterns of species richness and abundance of understorey birds using mist-net data as compared to results obtained with the call-based method (Bobo 2004, Waltert *et al.* 2005);
- To assess ecological correlates such as food availability, nesting sites, and indices of parasitism, fluctuating asymmetry, in order to detect key parameters for population development and pre-conditions for long-term suitability of different land use systems for forest bird populations;
- To document the role of land use systems other than near-primary forest in biodiversity conservation of tropical landscapes.

III.3. Research questions

The following questions are of special interest:

- What are the effects of different land use systems on the diversity and abundance of understorey birds? Are there correlations between species diversity and heterogeneity of habitats?
- How do these patterns differ from that of call-based methods?
- How does the impact of different land use systems on richness and abundance differ between the different taxonomic and guild groups of birds?
- Is there a correlation between understorey birds' species richness and abundance and food availability, level of predation, parasitism, fluctuating asymmetry and nesting sites?
- What are the indicator properties of birds for overall patterns of species richness?
- How does the proportion of endemic species or other species of conservation concern in the respective assemblages differ between the study sites?
- Which species are less sensitive to habitat changes and what are their characteristics to be able to successfully exploit disturbed habitats (e.g. body size, feeding guild)?
- What are the conflicts between biodiversity conservation interests and current land uses?
- What is the potential role of land use systems other than near-primary forest in biodiversity conservation of tropical landscapes with regard to the potential persistence of species of conservation concern?

III.4. Hypotheses

The hypotheses of this research are:

1. Species richness of understorey birds should decline with increasing disturbance as in Mbalmayo Forest Reserve, south-central Cameroon by Lawton *et al.* (1998) and in the Lore National Park, Central Sulawesi Indonesia by Schulze *et al.* (2004). Richness in some groups should be insensitive to extreme habitat modification and, not all groups/taxa would have maximum species richness in near-primary forest.
2. It has been shown that tropical lowland forest bird communities can be highly diverse and, equitability in abundance between species can be extremely high (Terborgh *et al.* 1990, Thiollay 1994). Abundance distribution in disturbed habitats, however, should follow log-series more than log-normal or broken-stick models (relationships between disturbance and abundance distribution e.g. in Johns 1992, Herremans 1995).
3. The species richness between certain taxa should be significantly correlated. This was found also by Schulze *et al.* (2004) in the Lore National Park, Central Sulawesi Indonesia. Some of the selected taxa/guilds should serve as good indicators for changes in the species richness of other groups/taxa. Particularly, endemism of a taxon should be highly correlated to endemism of other taxa.
4. Even if richness changes little with disturbance, trophic structure may alter, and characteristic species of primary forest may be replaced by species associated with disturbed habitats (Lawton *et al.* 1998). This should also be the case in our study.
5. In an ecologically complex primary forest, spot-diversity (on a few hectares) is very high due to the year-round availability of major resources (Terborgh *et al.* 1990). In disturbed habitats, this high alpha-diversity should be much reduced.
6. While the food availability and the nesting sites should decline with increasing disturbance, the level of predation, parasitism and fluctuating asymmetry should increase.
7. The body size (mass), more than the feeding guild, should be a decisive factor to determine the level of sensitivity of a species or group of species to habitat changes.

IV

THE STUDY AREA

The study took place in the Support Zone (SZ) of the Korup Project Area (KPA), at some five km from the North-Eastern boundary of Korup National Park (KNP). Together these two areas i.e. KNP and SZ, cover more than 6,600 km² within the South West Province of Cameroon.

IV.1. Korup National Park

IV.1.1. General

KNP covers an area of approximately 1,260 km². KNP is contiguous with Cross River National Park (Oban Division) in neighbouring Nigeria. Located at the centre of the Guinea Congolian forest refugium (Maley & Brenac 1998), KNP is reputed to be the best remaining example of this forest type and richer than any other African forest for which data is available (Richards 1952 in MINEF/KP 2002). The mammal fauna of KNP is fairly well documented, but other groups such as insects (excluding butterflies) and molluscs remain virtually unknown. The mammal fauna of KNP consists of 33 families with 161 different species (in MINEF/KP 2002). Korup region contains 84% of all known African primates (in Waltert *et al.* 2005) and holds an assemblage of endemic primates known as the Cameroon faunal group (see Oates 1996). In ornithological terms KPA is known to be the most diverse lowland site in Africa (Rodewald *et al.* 1994) with a total of 419 bird species recorded so far (Bobo *et al.* 2005) in 53 families. The Korup region is considered to be the most species-rich site for butterflies in Africa (Larsen 1997). Although only 480 species have been recorded so far, it has been suggested a potential of at least 950 species for this region (in MINEF/KP 2002). There are five villages for a total of around 1,500 individuals inside the park. KNP is universally recognised as a conservation area of international importance. It is known to be a biodiversity hotspot, a glacial refuge for many species, a centre of endemism, a centre of taxa diversity and a source of valuable phytochemicals (see MINEF/KP 2002).

IV.1.2. Brief land use history

Korup appears to have suffered very little human disturbance in the past and this is judged to have been a major factor in determining its present species richness (Gartlan 1986). West of Korup, in Nigeria, most of the forests have already been degraded or destroyed. To the north, a long period of human occupation has significantly altered the original climax vegetation. East of Korup, agriculturally rich areas have been extensively cultivated for at least the past 200 years. Therefore Korup appears to be a relatively pristine island surrounded by forests that have all been substantially altered by human activity (in MINEF/KP 2002). Large oil palm plantations of some 60 km² extent and belonging to the parastatal PAMOL Plantations Ltd. can be found around Mundemba, bordering the park.

IV.1.3. Threats to KNP

KNP is facing some threats, which include (in MINEF/KP 2002):

- The encroachment in a number of areas along the park boundary, or where the boundary itself is contested. Encroachment occurs solely for the cultivation of oil palms, cocoa and food crops, not for the purposes of human settlement. Fortunately Korup soils are unsuitable for agriculture and have been largely ignored by surrounding farmers. The area is unsuitable for oil palm production due to the poor water-retention properties of the sandy soils and the low levels of solar radiation. It is too wet and the terrain too rugged for the cultivation of rubber and too far from commercial markets for bananas. It is too infertile for coffee and cocoa and the altitude is too low for tea.
- The poaching, mostly illegal hunting by night or snaring of ‘bushmeat’ and the gathering of a wide range of non-timber forest products (the latter posing less of a threat to ecological integrity). The most important forest resources (bushmeat, eru, chewing stick and bush mango) are generally sought for the purposes of generating income, although a wide variety of less important forest resources are collected for subsistence use. Mainly due to problems of inaccessibility and insufficient game guards large areas of the park have been severely neglected or abandoned altogether including the greater part of the northern and eastern sectors, most park villages and the western boundary areas. Large gangs of well-organised and heavily armed poachers, based in Nigeria, operate freely (Lennon 1997).

- The presence of five villages inside the park namely Bareka Batanga, Bera, Erat, Esukutan and Ikenge for a total population of around 1,500 individuals who rely heavily on hunting, trapping and exploitation of NTFPs to sustain their livelihoods with significant negative impact on the park (Vabi 1999).
- There is also little threat due to bush fire or from logging.

IV.2. The Support Zone

The SZ was established in 1987 by the Korup Project to reduce pressure on KNP by improving the sustainability of surrounding land-use practices. Covering an area of 5,353 km² with no legal status (see Fig. IV.1.), the boundaries of the SZ include all the area south of KNP from Isangele east to the Rumpi Hills, north-east to the Kumba to Nguti road including Nta Ali Forest Reserve and north-west to Eyumojock including the Ejagham Forest Reserve. The SZ contains more than 180 villages and has a population of roughly 50,000 (Bijnsdorp 2001).

IV.3. The studied plots

Our plots were situated in the North-eastern part of the SZ, specifically the area between Abat-Mgbegati-Basu-Bajo which lies in between 5°21'N and 5°25'N and 9°09'E and 9°13'E (see Fig. IV.1).

With the help of local guides, sites that fit very well with criteria mentioned in §IV.5. and from which a clear trend in land use change could be defined, were selected. This selection was based on visual observations in the field to guarantee certain homogeneity of plots for a same land use system. In each land use system or stratum, six study sites (= points) were established. A total of 24 study sites (or „sampling stations”) were selected representing the four habitats. Topographically, all study sites were situated at an altitude of about 250 m above sea level (asl.).

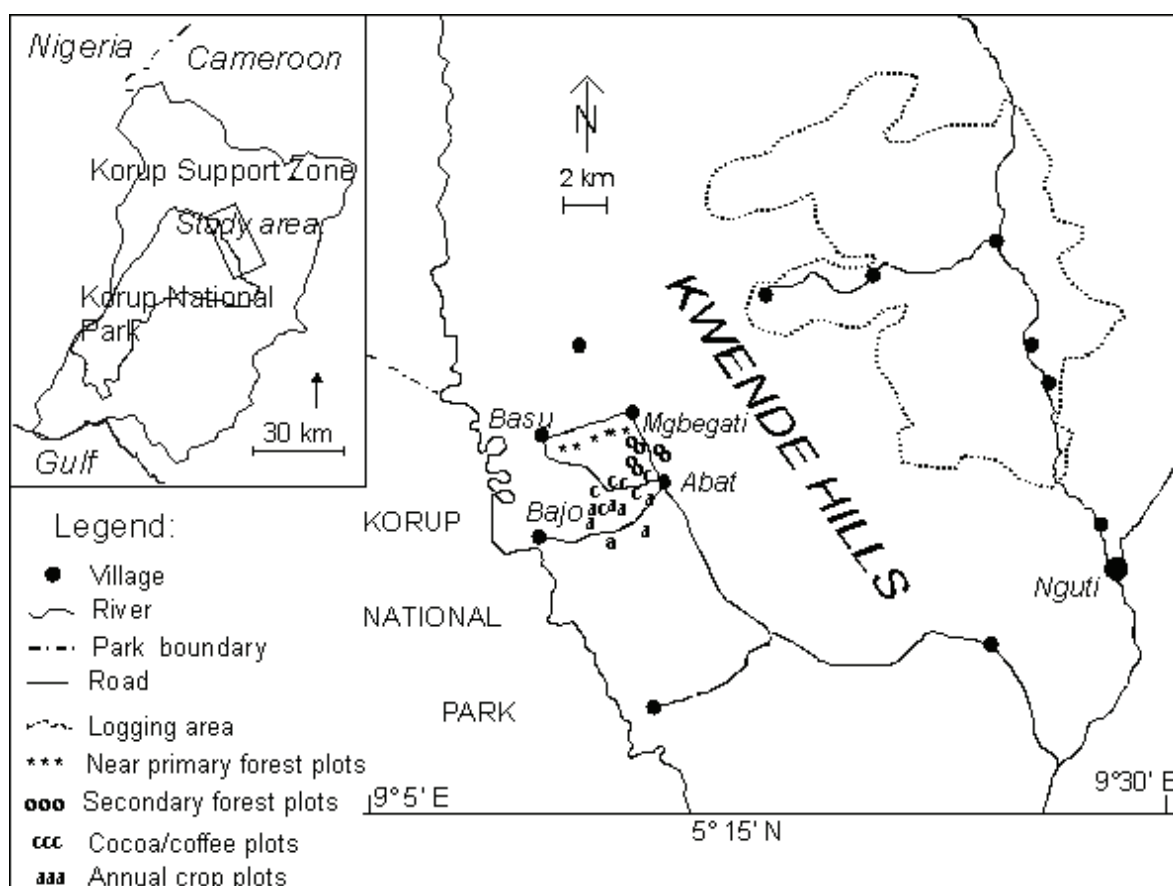


Figure IV.1.: The study area.

IV.4. Biophysical conditions

IV.4.1. Climate, topography, geology and soils

Climatic data for the study area is available from Nguti which is not more than 20km distant from any of the visited sites, and at the same latitude ($5^{\circ}21'N$). The average annual rainfall and temperature between 1993 and 2002 are respectively 4,536 mm and $27.4^{\circ}C$ (Nambu 2003). August is the wettest month with 782 mm of rain while February is the driest month with 4 mm of rain. The period between December and February can be considered as ecologically dry (see Fig. IV.2). The average relative humidity is 87%.

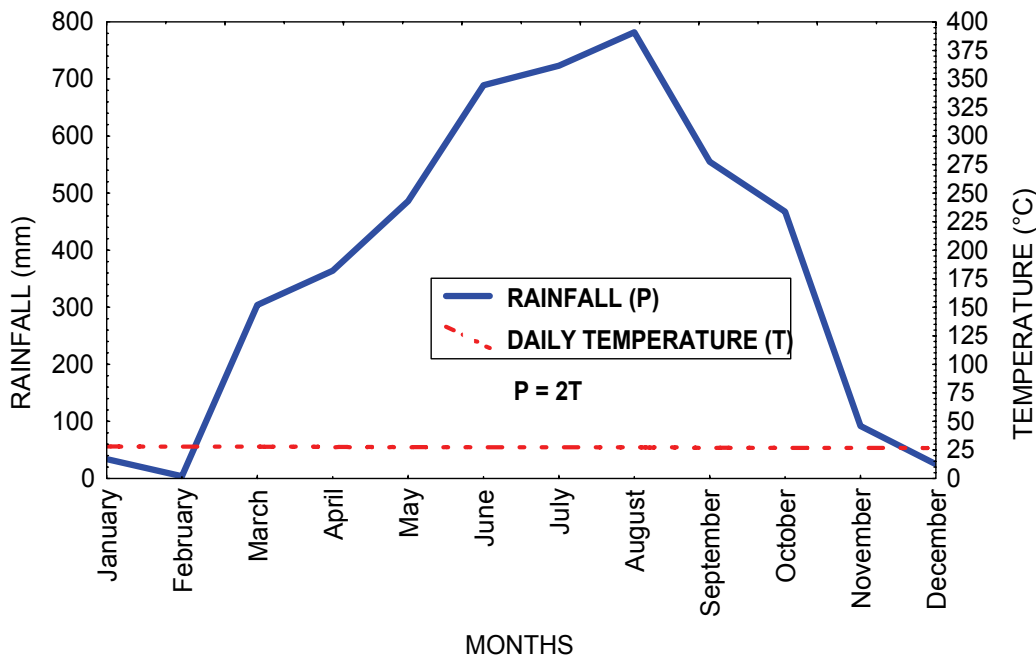


Figure IV.2.: Climatic diagramme for Nguti (average for the period between 1993 and 2002). $P < 2T$ indicates an ecologically dry period.

The study area is situated between the Eastern boundary of KNP and the Nkwende hills. Its western part is of lower elevation ranging from 125 m near Bajo to 448 m at Ayong. Except for some of the Bake tributary streams, which are incised, the topography is generally undulating to rolling. Discontinuous terraces occur along the Bake River. Its eastern limit is rugged and the topography becomes steeper, rolling to dissected, particularly around the Nkwende Hills and Munaya River (in MINEF/KP 2002).

Six main geological types have been identified from the SZ including recent alluvium, Cretaceous sediments, Mio-Pliocene sediments, Pre-Cambrian gneiss, Tertiary (older) basalt and Tertiary dolerite (MINPAT 1989). Our plots are located in an area of basalt lava flow, at a lower altitude and emanating from the Nkwende Hills.

The soils of our study area were dominated by clayey, with less stoney due to the basalt parental rock, suitable for farming systems, in which food crops, tree crops and forest trees are closely integrated. Food cropping should alternate with sufficient fallow to ensure the maintenance of soil fertility (LRDC 1987).

IV.4.2. Hydrology and drainage

There are two major drainage systems in our study area (in MINEF/KP 2002).

- The Bake-Munaya River System drains the western parts of the study area through tributaries such as the Libangenie, Maili, Marube, Ma, Mameli, Mohib, Bakwe, Bagodo, Bayong Ayib, Bate, Akarem and Akam;
- The Manyu River System drains the central and eastern sectors of our study area through tributaries such as the Ehope-Mamfue, Bakogo, Mam, Mbu, Bali, Badi and Bachi.

IV.4.3. Flora and fauna

Our study plots are situated in the lowland evergreen forest (below 400 m asl.) that belongs to the Atlantic Biafran Forest which is known to be riched in Caesalpiniaceae, with many poorly known, rare and endemic plant species. Towards the east on the Kwende hills, which rises above a 1,000 m altitude, a combination of piedmont semi-deciduous and submontane forests can be expected.

The fauna of our study area is similar to what is found in KNP. However, the hunting pressure is high and it is likely that certain species such as the leopard, golden cat, yellow-backed duiker and giant pangolin are locally extinct while others such as red colobus, drill and chimpanzee remain vulnerable to extinction (Usongo 1995, Waltert *et al.* 2002). Most larger mammals are already rare and the forest is almost empty. Our observations indicate that bats and big birds like raptors, turacos, and hornbills are now the main target for subsistence hunting, particularly during the dry season. During our study period, blue duikers, putty-nosed and crowned monkeys were but rarely seen in the forest which is still in good state (see also Waltert *et al.* 2002). Other signs of the emptiness of the forest are the total absence of traps and the presence of very old remains of cartridges in primary forests, and many old abandoned fence traps in the secondary bushes. However, due to its rugged topography, the Kwende hills, located east of our study plots, are reputed to harbour significant population of drill and chimpanzee (in MINEF/KP 2002).

IV.4.4. Human population, cultural and linguistic groups

Of the 50,000 inhabitants of the SZ, very few belong to our study area big as 40 km² and where a personal estimation leads to a population of 1,000 inhabitants. The reasons for this

low population density are the remote and difficult accesses to villages particularly during the rainy season and to the high rates of exodus (Devitt 1988), mostly in the direction of larger towns such as Mundemba, Kumba and Tiko, to the plantations of the South West Province for those looking for jobs, and towards the Kumba-Mamfe road and the Kumba corridor for those wishing to establish farms (Malleson 2000). The decline in cocoa and coffee markets has encouraged many of the young and middle-aged men to leave the area in search of work in plantations and urban areas. In recent years however declining job opportunities in urban areas have led many young and middle-aged men to return to their former villages where they now earn a living based on hunting and trapping.

The Korup area contains a diverse range of ethnic groups including the Oroko, Korup, Ejagham, Balong, Bassossi, Upper Bayang and Mbo (Vabi 1999). Although there are strong historical, linguistic and cultural similarities between these groups there are also strong differences. Our study area is the domain of the Ejagham ethnic group, mainly constituted of the Obang people. Some other ethnic groups, namely the Mbo, Bassossi, Upper Bayang and the Balong are also found northeast of the Park (Vabi 1999). The lingua franca in the Korup area is Pidgin English, spoken by almost everyone (Malleson 2000).

IV.5. The studied land use systems

Our research was carried out in four different land use systems or habitats known as (Table IV.1.):

- a) Near-Primary forest (NF), with very little or no anthropogenic activities;
- b) Secondary Forest (SF), where anthropogenic impacts is very high, with a canopy cover of less than 50%;
- c) Agroforestry system (CF), where the land has been used for cocoa/coffee/plantain production, with few natural trees remaining;
- d) Annual cultivation (AC), where the land has been used for subsistence crop production (cassava, yams, maize, groundnut, ...), with very few natural trees left.

Table IV.1.: Vegetation characteristics of the four studied habitats.

Habitat type	Description
Near-primary forest	Canopy height 35 – 45 m, canopy cover 75-95%, sparse undergrowth
Secondary forest	>18 years old forest regrowth and degraded forest along roads, average canopy cover 40 – 60%, average canopy height 25 – 30 m, dense undergrowth
Agroforestry systems	12 – 18 years old cocoa/coffee plantations, natural shade trees of up to 25 m height, dead trees
Annual cultures	Annual cultivations, mainly maize and cassava, only occasional trees, young fallow vegetation (farmbush and <i>Chromolaena</i> thickets), dead trees

PART II

**UNDERSTOREY BIRD COMMUNITY
STRUCTURE, SPECIES RICHNESS AND
ABUNDANCE ALONG A GRADIENT OF
FOREST CONVERSION**

UNDERSTOREY BIRD COMMUNITY STRUCTURE, SPECIES RICHNESS AND ABUNDANCE ALONG A GRADIENT OF FOREST CONVERSION

Abstract

The debate on how much biodiversity can be sustained in disturbed forests particularly in the Afro-tropical context is still ongoing. This paper describes patterns of species richness, abundance and structure of forest understorey birds and compares the overall species richness patterns found with that of a previous call-based method study in the Korup region, Cameroon. We investigated understorey birds with a 102 m net-line set for 22 h in 24 plots distributed equally over four habitat types with increasing degree of disturbance, including two natural forest habitats and two land use systems. We found that the number of captured individuals was not significantly affected by habitat type. Based on rarefaction analysis, overall species richness showed a steady increase with increasing habitat modifications. But, different bird groups responded in different ways: biome-restricted, Nectariniidae, insectivorous, lower stratum birds and small foliage gleaners showed a steady increase in species richness with increasing habitat modifications; while species richness of Pycnonotidae, mid-stratum, omnivorous and ant-following birds seemed to be similar between habitat types. No clearly defined patterns were found in large and medium-sized foliage gleaners. Species similarity was higher among natural habitats than among land use sites, and low between natural habitats and land use systems. Apart from the mist-netted bird community found in agroforestry systems that differed significantly from a lognormal distribution, abundance distribution in near-primary forest, secondary forest and annual cultures did not differ significantly either from a lognormal distribution or from a logseries distribution. A weak but significant, negative relationship was found between the extent of the species' geographic range and their preference for near-primary forest. A modest, significantly positive correlation was found between body mass and preference for near-primary forest. A weak and significant, positive correlation was found between average foraging height and relative preference for annual cropland. While captures of insectivores were significantly higher in natural habitats than in land use types, granivores, omnivores and to some extent frugivores showed the opposite pattern. By comparing pattern of overall

capture rates with that of marked individuals along the habitat gradients, we could conclude that the number of adult territory owners in insectivores should be higher in near-primary forest or natural habitats than in land use systems (see chapter VIII). Surprisingly, different species richness patterns, a much higher species turnover and a much lower habitat specificity were found when compared with results of the call-based method. Our results point out that, compared to primary forest, in degraded habitats individuals of true forest bird species appear outside their normal territories mainly during the period of stress. To draw definitive conclusions on tropical forest bird structure, richness and diversity along a gradient of forest disturbance, mist-net and call-based methods should be parts of the same study.

Key words: Birds conservation, Call-based method, Land use systems, Mist-netting, Southwest Cameroon, Sub-Sahara Africa, Tropical rainforest, Understorey birds' diversity and structure.

V.1. Introduction

Each 1% reduction of natural area will cost about 1% of steady-state diversity and preserving small tracts of wild habitat can only delay these reductions (Rosenzweig 2003). The conversion of tropical primary forests into various land use systems has serious impacts on the distribution, community structure and population characteristics of flora and fauna (e.g. van Gemerden 2004; Waltert *et al.* 2005b). In the African context, highest conversion rate is reported from Côte d'Ivoire where many forest reserves have been occupied illegally by farmers to grow food and cash crops such as coffee and cocoa (Parren & de Graaf 1995) and, poaching is considered to be the major threat for large birds and mammals (McGraw *et al.* 1998). In Cameroon, most of the primary forests have already been damaged by logging, which has also opened ways to cocoa/coffee plantations and slash and burn agriculture in rural areas.

The question, how much biodiversity can be found in agricultural landscapes, has been investigated all over the tropics (e.g. Estrada *et al.* 1997, Greenberg *et al.* 1997a, Greenberg *et al.* 1997b, Daily *et al.* 2001, Hughes *et al.* 2002, Schulze *et al.* 2004, Waltert *et al.* 2004, 2005a) but to date not much has been done in tropical Africa (e.g. Devineau 1984, Malaisse 1984, Kofron & Chapman 1995, Plumptre 1997, Lawton *et al.* 1998, Zapfack *et al.* 2002, Waltert 2000a,b, Waltert *et al.* 2005b, Bobo *et al.* 2006a,b), and very few of these studies

concerned understorey forest birds (e.g. in Southeast Asia by Waltert *et al.* 2005a, in tropical Africa by Waltert 2000a,b).

Our aim is to describe patterns of species richness, abundance and structure of understorey birds between two types of natural habitats (near-primary and secondary forests) and two types of land use systems (agroforestry systems and annual cultures), and to assess their ability to persist in modified habitats. This section also aimed at comparing or providing additional information on the bird community to the previous call-based method study on the same study sites (Bobo 2004, Waltert *et al.* 2005b), because this last method is known to be incomplete, particularly as far as understorey birds are concerned as they are generally shy and skulking species, thus difficult to record.

Based on earlier studies in Central Sulawesi, Indonesia (Waltert *et al.* 2005a), in the Bossematié forest, Eastern Côte d'Ivoire (Waltert 2000a,b) and in Southwestern Cameroon using the called-based method (Bobo 2004, Waltert *et al.* 2005b), we hypothesised that (1) overall understorey bird species richness and abundance will be higher in natural habitats than in land use systems, (2) different understorey bird groups/guilds will respond in different ways to habitat modifications, (3) species composition will change along the habitat gradient, with true forest species being gradually replaced by species associated with disturbed habitats, (4) species richness patterns of mist-netting will be different from that of the call-based method, (5) understorey birds structure patterns will not be different from that of other forest birds communities in the Afrotropical context (e.g. in Waltert 2000a).

V.2. Methods

V.2.1. Data collection

In each of the 24 sampling stations, mist-netting was conducted from January 15th to March 07th, 2006 as this method is known to be less observer-dependent than visual or acoustical means (Waltert 2000a) and is a major component of breeding bird censuses in tropical rainforest (Terborgh *et al.* 1990). A combination of 6 and 12 m long mist-nets, 2.5 m high with 16 mm mesh, was used to produce a single 102 m net line for which narrow trails were cut. The net line was opened for 22 hours i.e. from 15h00 to 18h00 on the first day, from 6h00 to 18h00 on the second day and from 6h00 to 13h00 on the third day. The whole net line was then moved to the next plot, resulting in a total of six 102 m lines per habitat and 24 (6 × 4 study sites) in total. The sampling effort amounted to *c.* 132 net-hours for each habitat and *c.*

528 net-hours in total. Net lines were checked every hour. Birds were identified and sides of their two tarsi were painted referring to each study site, with a waterproof bold marker, to be able to distinguish recaptured individuals from one site from those of different study sites. Birds found at 18h00 in mist-nets were kept in cotton bags until 7h00 the next day to avoid possible disorientation of animals when released in the dark.

A comparable study using the call-based method was done on the same study sites from January to March 2004 and results were already published in Bobo (2004) and Waltert *et al.* (2005b).

V.2.2. Data analysis

Diversity of understorey bird community was calculated using various diversity indices, for each guild/group and for the overall mist-netted community. Calculations were based on captured individuals with the help of Colwell (2000), by randomising 100 times, in which formulas from the following sources are used such as Shannon-index (H_s), Evenness ($H_s/\ln S$), Simpson index ($1/D$) after Magurran (1988) and William's alpha after Fisher *et al.* (1943), cited in Magurran (1988).

The main assumption in using the Shannon index is that randomness of the sample, e.g. no differential attraction of a species to a trap (such as moths to a light trap), must be given. Compared to other indices, Shannon has a moderate capacity to discriminate between communities and is mainly influenced by abundances of the medium abundant species (Magurran 1988). Whereas Shannon index is less influenced by dominance, the Simpson index is very sensitive to the abundance of the most common species. It gives the probability of any two individuals drawn at random from a finite community belonging to different species. The ratio of observed to maximum diversity, comprises between 0 and 1, can be taken as a measure of evenness, and provides better opportunities for comparisons.

As Simpson index is not sensitive to species richness, the logseries index was also calculated. This index is not much dependent on sample size and possesses a good discrimination ability between communities.

We have chosen an observed frequency distribution or a species-abundance distribution to summarize our understorey bird data because of our large collection (1307 individuals) that contains numerous species (93 species), of which several have exactly one individual (22 species), several have exactly two individuals (16 species), and so on (read also Shepard

2001). To describe species-abundance distributions of samples, species-abundance models were fitted to expected distributions (lognormal and logseries) by chi-square Goodness of fit tests. Expected distributions were calculated with the software LOGSERIE and LOGNORM inserted in Krebs (1989).

We compared rarefied understorey bird species richness between habitats for different bird groups or guilds using the Hurlbert rarefaction method (Hurlbert 1971) to standardise sample size (= number of collected individuals) and plotted rarefaction curves showing the expected number of species for a given number of specimens for each group. Total rarefied understorey bird species richness was evaluated, and also when most abundant species, i.e. species with more than 100 individuals each, are excluded from the sample. We then computed rarefied understorey bird species richness for insectivorous, nectarivorous (family Nectariniidae) and omnivorous guilds. We also analysed separately the guild of ant-following species, species restricted to the Guinea-Congolian Forest Biome (see Fishpool & Evans 2001), as well as species from different vertical strata (mid- and lower strata), the family Pycnonotidae (bulbuls) as they are mainly forest-dwellers, and different sizes of insectivorous birds categorised in large foliage gleaners (> 40 g), medium-sized foliage gleaners (20 – 40 g) and small foliage gleaners (< 20 g). It was not possible to compute rarefied species richness for guilds like carnivorous, frugivorous and granivorous, as well as for the upper-stratum birds group, as their sample sizes (n) were too small (see Table V.1.).

We also calculated beta-diversity between different sites using the classic Sorensen (qualitative) index (Magurran 1988) as well as the Morisita Horn index, using the software EstimateSWin7.0.0 of Colwell (2000). We used the Morisita Horn index in a multidimensional scaling (StatSoft 2001) and ordinated our study sites two-dimensionally to depict understorey bird similarity between habitat types.

For each study site, abundance was calculated as the total number of individuals detected during the 22 h that the net line was opened. Two-hundred-twenty-one recaptured individuals were excluded from the analysis to avoid pseudo-replication. One-way ANOVA was done to detect species-specific responses to habitat type. We applied the sequential Bonferroni technique (Holm 1976) to reduce the probability of statistical type I errors by calculating table-wide significances α for each species and listed only those species with $\alpha \leq 0.05$. Using post-hoc tests (Tukey's honest significant difference test), single species were assigned to different response categories.

Spearman-rank and Gamma-rank correlations, one-way ANOVA and all other statistical analyses were performed using STATISTICA 6.0 (StatSoft 2001).

Table V.1.: Total number of individuals detected per habitat type for each studied guild/group during the 528 net-hours spent for this study. Recaptured individuals, 221 in number, are excluded to avoid pseudo-replication.

Feeding guild/group	Habitat type			
	NF	SF	CF	AC
All species	279 (270)	354	327	347
All species**	238	223	124(125)	246
Biome restricted	190	198	104 (100)	135
Insectivores	229	210	98 (90)	131
Ant-followers	127	126	38	10 (10)
Carnivores	3	0*	2	0
Frugivores	0*	4	5	7
Granivores	5*	6	11	61
Nectarivores	24 (25)	44	78	72
Omnivores	18 (20)	90	133	76
Upper-Strata	4*	13	11	13
Mid-Strata	66 (60)	150	176	139
Lower-Strata	209	191	140 (140)	195
Pycnonotidae	85 (85)	153	159	106
Large foliage gleaners	18	19	9 (9)	17
Medium-sized foliage gleaners	135	114	37 (30)	39
Small foliage gleaners	76	77	52 (50)	75

Notes: *: Number of individuals too small to compute rarefied species richness; ** Overall number of individuals when species with more than 100 individuals each (i.e. Little Greenbul, Yellow-whiskered Greenbul and Olive Sunbird) are excluded; (): Total number of individuals considered when computing rarefied species richness.

V.2.3. Theory (see Shepard 2001)

One of the problems we encounter is that ecological theory can come up with very elegant, mathematically sound concepts that prove impossible to implement in the real world. One approach is to apply models of species-abundance distributions as in the composition of species population; there is often several similar species of apparently similar requirements, but with each of the species greatly differing in their relative abundances. Sometimes the

differences can be explained in terms of habitat differences: the abundance of a species may be proportional to the relative amount of space available to it (in terms of suitable habitat) (Shepard 2001).

Although the value of species-abundance models for applied ecological research is still subject of discussions (see Nummelin 1998, Basset *et al.* 1998, Watt 1998), it has been admitted that, when adequately interpreted, they can be quite useful in the analysis of community structure patterns (Hill & Hamer 1998). Species-abundance distribution can be predicted by a first kind of model called the “resource apportioning models”, specifically for our case study the **Overlapping Niche Model** that explain the way in which coexisting species subdivide among themselves some necessary resource which is assumed to be the limiting factor (and the same limiting factor for each species present) that sets a limit to each population’s size, while the **Niche Preemption Model** and the **Broken Stick Model** predict a community’s ranked-abundance (read also Shepard 2001). Models of the second kind are called “**statistical models**”: They consist of assumptions about the probability distributions of such variables as the numbers of individuals of each of several species in a given area, and their predictions are expressed as species-abundance distributions. Three examples of statistical models are the **Truncated Negative Binomial Distribution**, the **Logseries Distribution** and the **Lognormal Distribution**.

The majority of natural communities display a lognormal distribution, which is believed to indicate a large, mature and varied community (Magurran 1988). A lognormal distribution of relative abundance implies a concave (logarithmic) abundance-rank diagram for the “lower”-ranking species (i.e. the most common ones) and a convex curve for the “higher” ranking species. An extreme abundance form is the broken-stick abundance model, which reflects an even more equitable state being the biological correspondent of a uniform distribution. If a broken-stick distribution is found, there is incidence that an important ecological factor is shared more or less evenly between the species. For example in the Amazonian rainforest, predation was suggested to be likely responsible for the broken-stick distribution of bird species abundances (Thiollay 1994). The logseries distribution is often visible in immature or stressed communities, dominated by one or a few ecological factors, but can also be due to small sample sizes. In an (logarithmic) abundance-rank diagram, a logarithmic series distribution implies a straight line except for the “lower” ranking species. Lognormal and Logseries models have also been used in palaeo-biology to describe instable evolutionary periods (Stenseth 1979).

V.3. Results

V.3.1. Abundance and species richness (spot diversity)

During the 528 h that the 102 m mist-net line was opened, a total of 1,307 individuals (recaptured specimens are excluded) belonging to 93 species, were trapped. The number of individuals was not significantly affected by habitat type (one-way ANOVA, $F_{3,20} = 0.65$, $P = 0.59$): the numbers of individuals per sampling station were highest in SF (59.0 ± 11.9 ; mean \pm SD), slightly lower in AC (57.8 ± 23.5) and CF (54.5 ± 17.1), and lowest in NF (46.5 ± 13.6).

When excluding most abundant species from the analysis i.e. species with more than 100 individuals each (Little Greenbul, Yellow-whiskered Greenbul and Olive Sunbird), the number of individuals becomes significantly affected by habitat types (one-way ANOVA, $F_{3,20} = 3.19$, $P = 0.046$): the number of individuals per sampling station is highest in AC (41.0 ± 20.1), slightly lower in NF (39.7 ± 11.1) and SF (37.2 ± 7.4), and significantly lower in CF (20.7 ± 9.5).

Based on rarefaction analyses and data pooled per habitat (pooled data from six study sites each), overall understorey birds, even when most abundant species are excluded, biome-restricted, Nectariniidae, insectivores, lower stratum and small foliage gleaners showed steady increase species richness with increasing habitat modification: At standard sample size $n = 270$ individuals, overall species richness was highest in AC (47.7 ± 1.6), a bit lower in CF (44.2 ± 1.7), intermediate in SF (38.2 ± 1.5) and lowest in NF (30.7 ± 0.5) (see Figs. V.1. and V.2A.).

Overall observed species richness per sampling station was significantly affected by habitat types (On-way ANOVA, $F_{3,20} = 3.40$, $p = 0.038$), and no clear defined was found: Highest species richness was found in AC (mean \pm SD; 22.5 ± 6.0); it was slightly lower in SF (20.0 ± 2.1) and CF (17.3 ± 3.2), and was significantly lower in NF (16.3 ± 2.0) (Tukeys Honest Significant difference-Test, $p = 0.041$, see also Fig. V.11.).

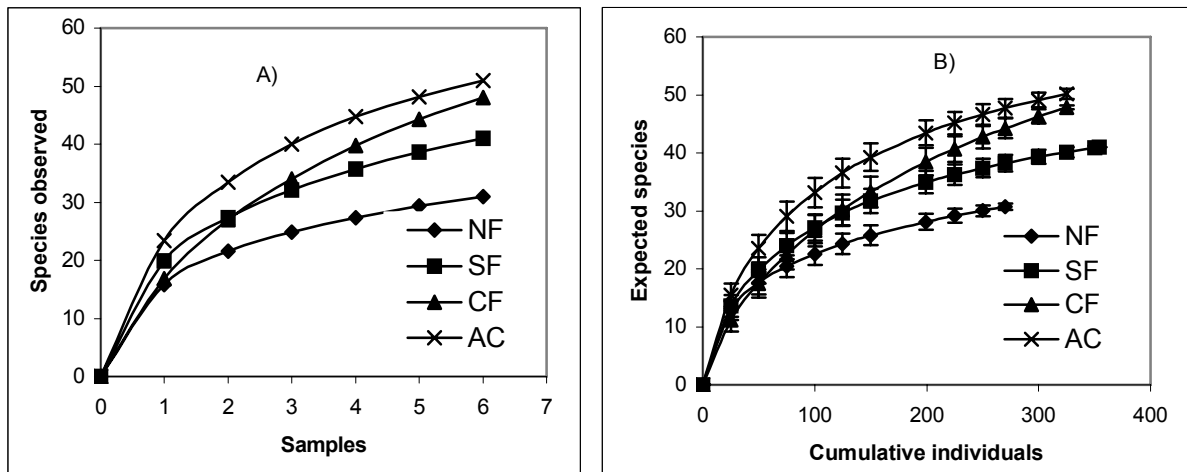


Figure V.1.: Sample- A) and individual- B) based accumulation of understorey bird species from mist-net samples in different habitat types. Habitats are: near-primary forest (NF), secondary forest (SF), agroforestry systems (CF) and annual cultures (AC).

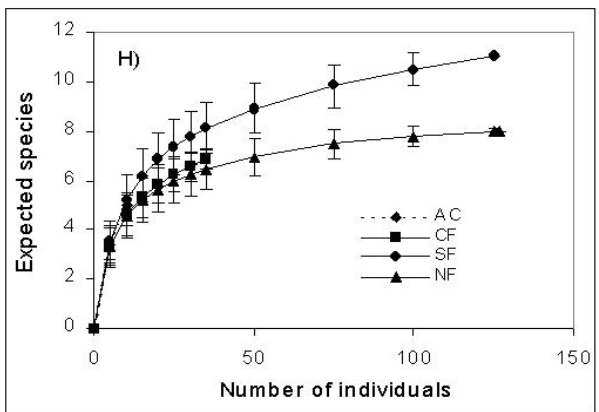
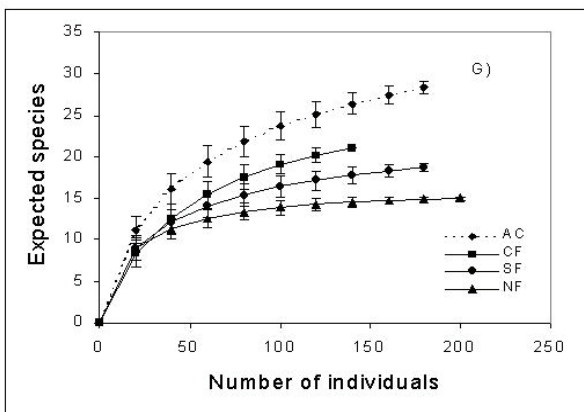
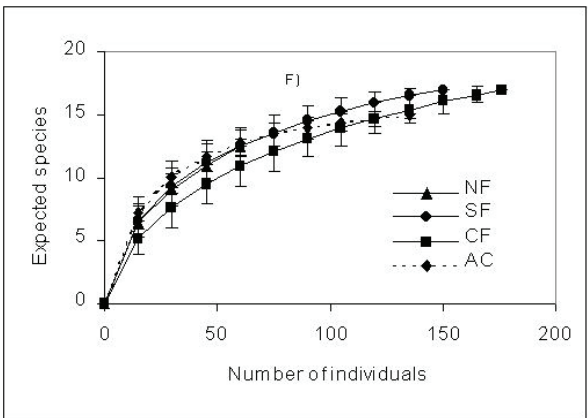
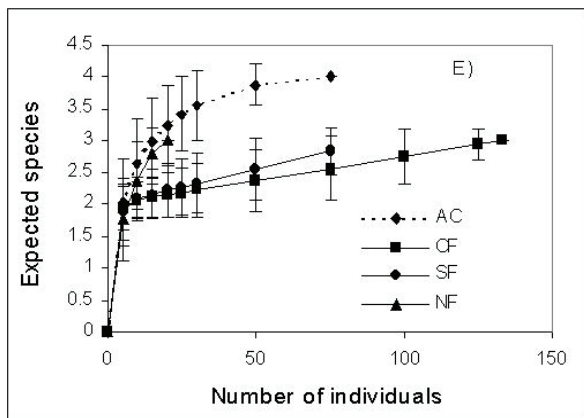
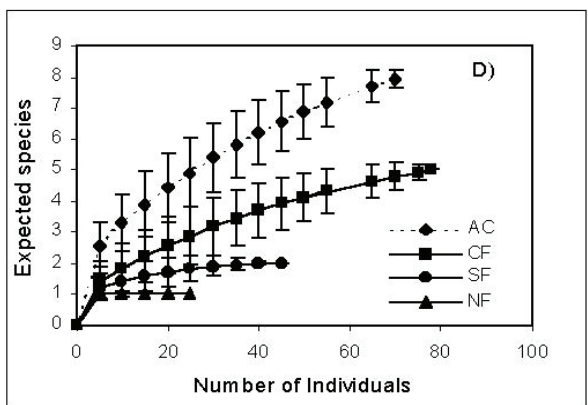
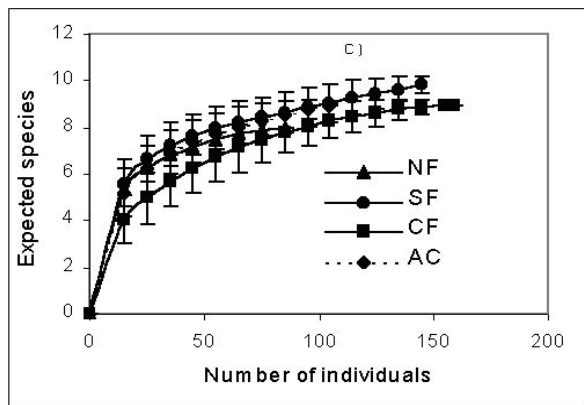
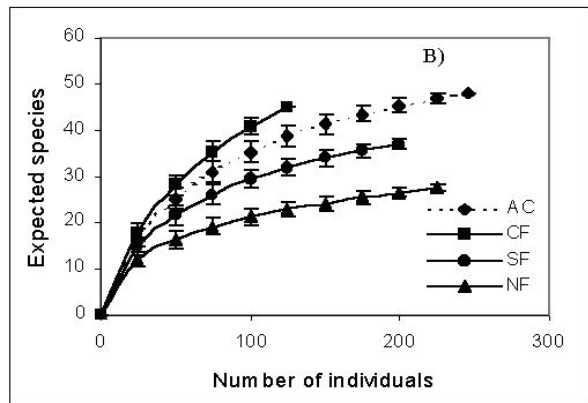
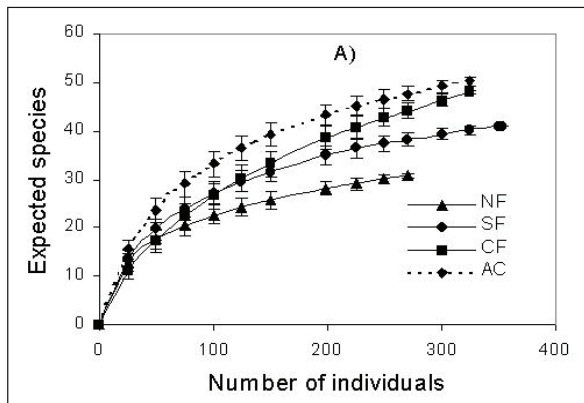
Observed and estimated species richness and Fisher's α -diversity showed similar trend; other diversity indices (Simpson, Shannon and Evenness) per habitat were also highest in AC, followed by NF/SF, but lowest in CF (see Table V.2.). When most abundant species are excluded from the analysis, the largest shared sample size between habitat types $n = 125$ individuals resulted in a highest expected species number of CF (45.0 ± 0.0), slightly lower in AC (38.7 ± 2.2), intermediate in SF (31.9 ± 1.9) and lowest in NF (22.8 ± 1.7) (see Fig. V.2B.). Similar results were obtained with almost all diversity parameters except the observed species richness, which showed highest species richness in AC (see Table V.2.). Biome-restricted species, at $n = 100$ individuals, showed lowest species richness in NF (18.6 ± 1.5), intermediate in SF (27.0 ± 1.9) and AC (27.9 ± 1.5), and highest in CF (33.5 ± 0.7) (Fig. V.2J.). Similar trend was observed with most diversity parameters (see Table V.2.). In Nectariniidae, at $n = 25$ individuals, highest species richness was found in AC (4.9 ± 1.1); it was lower in CF (2.9 ± 0.9) and SF (1.8 ± 0.4) and lowest in NF (1.0 ± 0.0) (see Fig. V.2D.). Similar trend was observed with other diversity parameters (see Table V.2.). In insectivores, at $n = 90$ individuals, highest species richness was found in CF (30.0 ± 0.9); it was slightly lower in AC (27.6 ± 1.5) and SF (25.6 ± 1.9) and lowest in NF (18.3 ± 1.6) (Fig. V.2I.). Fisher's α -diversity showed similar trend. Observed and estimated species richness were highest in SF, slightly lower in CF and AC and lowest in NF. The other diversity parameters also showed lowest species richness in NF, but which increase with increasing habitat

modifications (see Table V.2.). Lower stratum bird group, at $n = 140$ individuals, showed highest species richness in AC (26.4 ± 1.4), intermediate in CF (21.0 ± 0.0) and SF (17.8 ± 1.0), and lowest in NF (14.5 ± 0.6) (Fig. V.2G.). Fisher's α -diversity, observed and estimated species richness showed similar trend. The other diversity parameters showed lowest species richness in CF (see Table V.2.). Small foliage gleaners, at $n = 50$ individuals, showed highest species richness in CF (15.8 ± 0.5) and AC (13.8 ± 0.9) and lowest in SF (11.7 ± 0.9) and NF (10.7 ± 1.2) (Fig. V.2M.). Almost all the diversity parameters indicated similar trends (see Table V.2.).

Species richness in Pycnonotidae, based on largest shared sample size between habitat types $n = 85$ individuals, were similar between habitat types: however it seems to be highest in SF (8.7 ± 0.9), almost equal to AC (8.6 ± 0.6), slightly lower in NF (8.0 ± 0.0) and CF (7.8 ± 0.9) (Fig. V.2C.). The same result was observed for mid-stratum bird group at $n = 60$ individuals: however it seems to be highest in AC (12.7 ± 1.1), almost equal to SF (12.5 ± 1.4), NF (12.4 ± 0.7) and slightly lower in CF (10.9 ± 1.6) (Fig. V.2F.). At $n = 20$ individuals, species richness of omnivorous birds was highest in AC (3.2 ± 0.6), almost equal to NF (3.0 ± 0.0) and slightly lower in SF (2.2 ± 0.4) and CF (2.1 ± 0.4) (see Fig. V.2E.). In ant-following birds, at $n = 10$ individuals, species richness was highest in SF (5.2 ± 1.0), almost equal to AC (5.0 ± 0.0) and slightly lower in CF (4.6 ± 0.9) and NF (4.5 ± 0.9) (see Fig. V.2H.). For each of these bird groups, each diversity index showed a different unclear trend along the gradient of forest disturbance (see Table V.2.).

There were no clear defined patterns in large and medium-sized foliage gleaners: At $n = 9$ individuals, species richness of large foliage gleaners was highest in CF (5.0 ± 0.0), intermediate in SF (3.7 ± 0.8) and AC (3.4 ± 0.9), and lowest in NF (2.5 ± 0.5) (Fig. V.2K.). At $n = 30$ individuals, species richness of medium-sized foliage gleaners was highest in SF (10.3 ± 1.3) and in AC (10.2 ± 0.8), and lowest in NF (7.1 ± 0.8) and in CF (6.9 ± 1.1) (Fig. V.2L.). All diversity indices revealed similar results (see Table V.2.).

Although it was not possible to compute rarefied species richness of frugivorous, granivorous, carnivorous and upper-stratum birds, it is evident, from data presented in Table V.1., that annual cultures or degraded habitats in general are richer than natural habitats, except carnivorous birds that seem to show highest richness in NF.



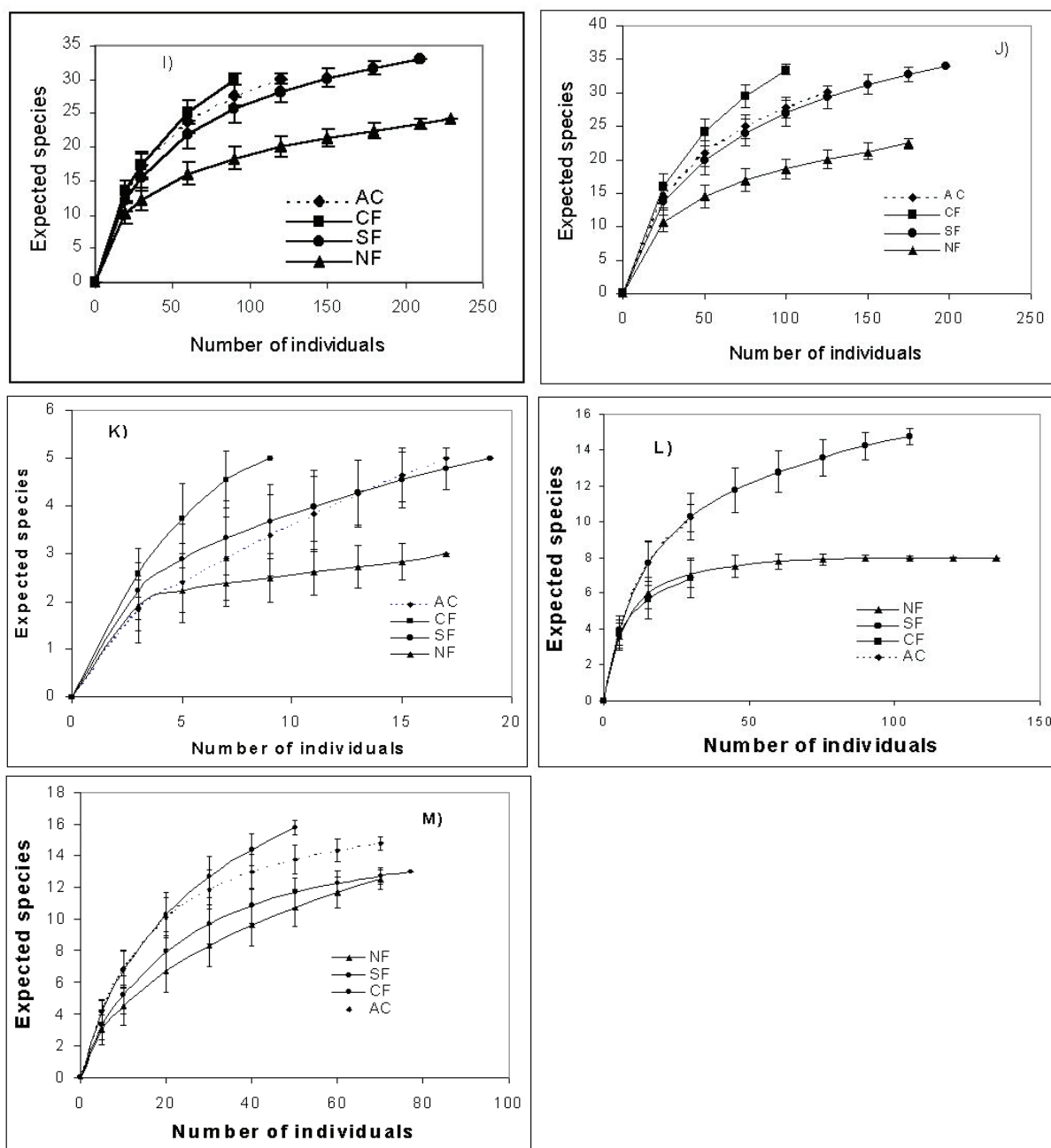


Figure V.2.: Rarefaction curves (Hurlbert 1971) for understorey bird data, pooled by habitat type for A) all species, B) all species excluding most abundant ones (i.e. species with more than 100 individuals each), C) Pycnonotidae, D) Nectariniidae, E) Omnivorous, F) Mid-strata, G) Lower strata, H) Ant-followers, I) Insectivorous, J) Biome Restricted species, K) Large foliage gleaners (> 40 g), L) Medium-sized foliage gleaners (20-40 g), M) Small foliage gleaners (< 20 g). The standard deviation for each expected species number estimate is given as measure of variation. See Fig. V.1. for abbreviations of habitats.

Table V.2.: Observed species richness, diversity indices and first order Jackknife species richness \pm SD per habitat for all understorey bird species and for different groups/guilds separately.

Understorey bird groups/guilds	Diversity parameters	Near-primary forest	Secondary Forest	Agroforestry systems	Annual cultures
All species	Observed species (<i>S</i>)	31	41	48	51
	Diversity Fisher's α	8.92	11.99	15.51	16.49
	Diversity Shannon (<i>Hs</i>)	2.84	2.98	2.65	3.28
	Diversity Simpson (<i>1/D</i>)	13.45	13.13	7.31	17.29
	Evenness <i>Hs/ln S</i>	0.83	0.80	0.69	0.83
	Estimator Jack 1	39.33 \pm 1.67	53.5 \pm 1.71	66.33 \pm 2.79	65.17 \pm 5.39
All species*	Observed species (<i>S</i>)	28	38	45	48
	Diversity Fisher's α	8.24	13.16	25.39	17.81
	Diversity Shannon (<i>Hs</i>)	2.7	3.08	3.47	3.39
	Diversity Simpson (<i>1/D</i>)	11.27	15.28	29.22	22.17
	Evenness <i>Hs/ln S</i>	0.81	0.85	0.91	0.88
	Estimator Jack 1	36.33 \pm 1.67	50.5 \pm 1.71	63.33 \pm 2.79	62.17 \pm 5.39
Biome restricted species	Observed species (<i>S</i>)	23	34	34	31
	Diversity Fisher's α	6.85	11.82	17.58	12.6
	Diversity Shannon (<i>Hs</i>)	2.48	2.92	3.18	2.99
	Diversity Simpson (<i>1/D</i>)	8.85	12.73	21.68	15.76
	Evenness <i>Hs/ln S</i>	0.79	0.83	0.90	0.87
	Estimator Jack 1	30.5 \pm 1.71	45.67 \pm 1.67	47.33 \pm 2.47	40.17 \pm 5.39
Insectivorous	Observed species (<i>S</i>)	21	33	31	31
	Diversity Fisher's α	6.76	11.0	15.63	12.82
	Diversity Shannon (<i>Hs</i>)	2.59	2.95	3.08	3.11
	Diversity Simpson (<i>1/D</i>)	10.48	13.71	19.72	20.72
	Evenness <i>Hs/ln S</i>	0.85	0.84	0.90	0.91
	Estimator Jack 1	30.67 \pm 2.11	43.83 \pm 2.01	42.67 \pm 2.11	41.00 \pm 5.16
Ant-followers	Observed species (<i>S</i>)	8	11	7	5
	Diversity Fisher's α	1.90	2.90	2.52	3.98
	Diversity Shannon (<i>Hs</i>)	1.66	1.91	1.63	1.42
	Diversity Simpson (<i>1/D</i>)	4.59	5.65	4.75	5.00
	Evenness <i>Hs/ln S</i>	0.80	0.80	0.84	0.88
	Estimator Jack 1	8.83 \pm 0.83	13.50 \pm 1.12	8.67 \pm 1.05	7.50 \pm 1.71
Pycnonotidae	Observed species (<i>S</i>)	8	10	9	9
	Diversity Fisher's α	2.16	2.40	2.07	2.35
	Diversity Shannon (<i>Hs</i>)	1.68	1.72	1.29	1.53
	Diversity Simpson (<i>1/D</i>)	4.67	4.28	2.72	3.16
	Evenness <i>Hs/ln S</i>	0.81	0.75	0.59	0.70
	Estimator Jack 1	8.83 \pm 0.83	12.50 \pm 1.12	9.83 \pm 0.83	10.67 \pm 1.67
Nectariniidae	Observed species (<i>S</i>)	1	2	5	8
	Diversity Fisher's α	0.21	0.43	1.19	2.3
	Diversity Shannon (<i>Hs</i>)	0.0	0.18	0.42	1.23
	Diversity Simpson (<i>1/D</i>)	1.0	1.1	1.21	2.73
	Evenness <i>Hs/ln S</i>	0.0	0.26	0.26	0.59
	Estimator Jack 1	1.0 \pm 0.0	2.0 \pm 0.0	6.67 \pm 1.05	10.5 \pm 1.12
Omnivorous	Observed species (<i>S</i>)	3	3	3	4
	Diversity Fisher's α	1.03	0.60	0.55	0.90
	Diversity Shannon (<i>Hs</i>)	0.56	0.66	0.70	0.80
	Diversity Simpson (<i>1/D</i>)	1.44	1.76	1.93	1.75
	Evenness <i>Hs/ln S</i>	0.51	0.60	0.64	0.58
	Estimator Jack 1	3.83 \pm 0.83	3.83 \pm 0.83	3.83 \pm 0.83	4.00 \pm 0.00

Mid-strata	Observed species (S)	13	17	17	15
	Diversity Fisher's α	4.85	4.93	4.64	4.27
	Diversity Shannon (H_s)	1.95	1.99	1.67	2.09
	Diversity Simpson ($1/D$)	5.39	4.52	3.33	5.12
	Evenness $H_s/In S$	0.76	0.70	0.59	0.77
	Estimator Jack 1	18.00 ± 1.29	23.67 ± 2.11	22.83 ± 2.01	17.50 ± 2.50
Lower strata	Observed species (S)	15	19	21	29
	Diversity Fisher's α	3.7	5.25	6.85	9.43
	Diversity Shannon (H_s)	2.33	2.35	2.02	2.78
	Diversity Simpson ($1/D$)	8.75	7.99	3.66	11.88
	Evenness $H_s/In S$	0.86	0.80	0.66	0.83
	Estimator Jack 1	16.67 ± 1.05	23.17 ± 1.54	26.0 ± 2.24	37.33 ± 3.57
Large foliage gleaners	Observed species (S)	3	5	5	5
	Diversity Fisher's α	1.03	2.21	4.63	2.39
	Diversity Shannon (H_s)	0.87	1.28	1.52	1.00
	Diversity Simpson ($1/D$)	2.39	3.42	7.2	2.03
	Evenness $H_s/In S$	0.79	0.79	0.94	0.62
	Estimator Jack 1	3.83 ± 0.83	6.67 ± 1.67	6.67 ± 1.05	8.33 ± 1.67
Medium-sized foliage gleaners	Observed species (S)	8	15	10	11
	Diversity Fisher's α	1.86	4.62	4.50	5.10
	Diversity Shannon (H_s)	1.87	2.26	1.96	2.13
	Diversity Simpson ($1/D$)	6.07	7.94	6.73	7.97
	Evenness $H_s/In S$	0.90	0.83	0.85	0.89
	Estimator Jack 1	8.00 ± 0.00	20.00 ± 1.29	13.33 ± 1.05	15.17 ± 2.39
Small foliage gleaners	Observed species (S)	13	13	16	15
	Diversity Fisher's α	4.51	4.48	7.90	5.64
	Diversity Shannon (H_s)	1.63	1.88	2.41	2.45
	Diversity Simpson ($1/D$)	3.04	3.95	9.68	11.06
	Evenness $H_s/In S$	0.64	0.73	0.87	0.90
	Estimator Jack 1	18.83 ± 2.39	17.17 ± 1.54	22.67 ± 2.47	17.50 ± 1.71

Notes: * Overall rarefied species richness when species with more than 100 individuals each (i.e. Little Greenbul, Yellow-whiskered Greenbul and Olive Sunbird) are excluded.

V.3.2. Species similarity between study sites (beta diversity)

Pairwise similarity of understorey bird species composition (mean Sorensen incidence index \pm S.D.) was highest among the six near-primary forest sites (0.65 ± 0.08) and the six secondary forest sites (0.6 ± 0.1). It was slightly lower among the six annual culture sites (0.54 ± 0.1) and lowest among the six agroforestry sites (0.43 ± 0.1). Similarity was still high between near-primary and secondary forest sites (0.60 ± 0.08), intermediate between secondary forest and agroforestry sites (0.43 ± 0.1), low between near-primary forest and agroforestry sites (0.39 ± 0.09), near-primary forest and annual culture sites (0.24 ± 0.065), secondary forest and annual culture sites (0.29 ± 0.07), agroforestry and annual culture sites (0.38 ± 0.09).

Two-dimensional ordination of study sites using abundance data in a correspondence analysis showed overlap between near-primary and secondary forests and very little overlap between agroforestry systems and annual cultures. Differences in species composition were large

between near-primary forest and land use sites (AC and CF), relatively small between secondary forest and agroforestry systems sites, and very small between agroforestry and annual crop sites (Fig. V.3A.). A one-way MANOVA of the sample scores extracted from the two-dimensional ordination revealed a significant difference in understorey bird species composition between the four habitats (Rao's $R_{6,38} = 11.38$, $P < 0.001$). When excluding the most left isolated sample (AC2) observed in Fig. 3A from the analysis, the one-sample way MANOVA of the sample scores extracted from the two-dimensional ordination still revealed a significant difference in understorey bird species composition between the four habitats (Rao's $R_{6,38} = 10.44$, $P < 0.001$). Differences in species composition between habitats were almost the same as previous (see Fig. V.3B.).

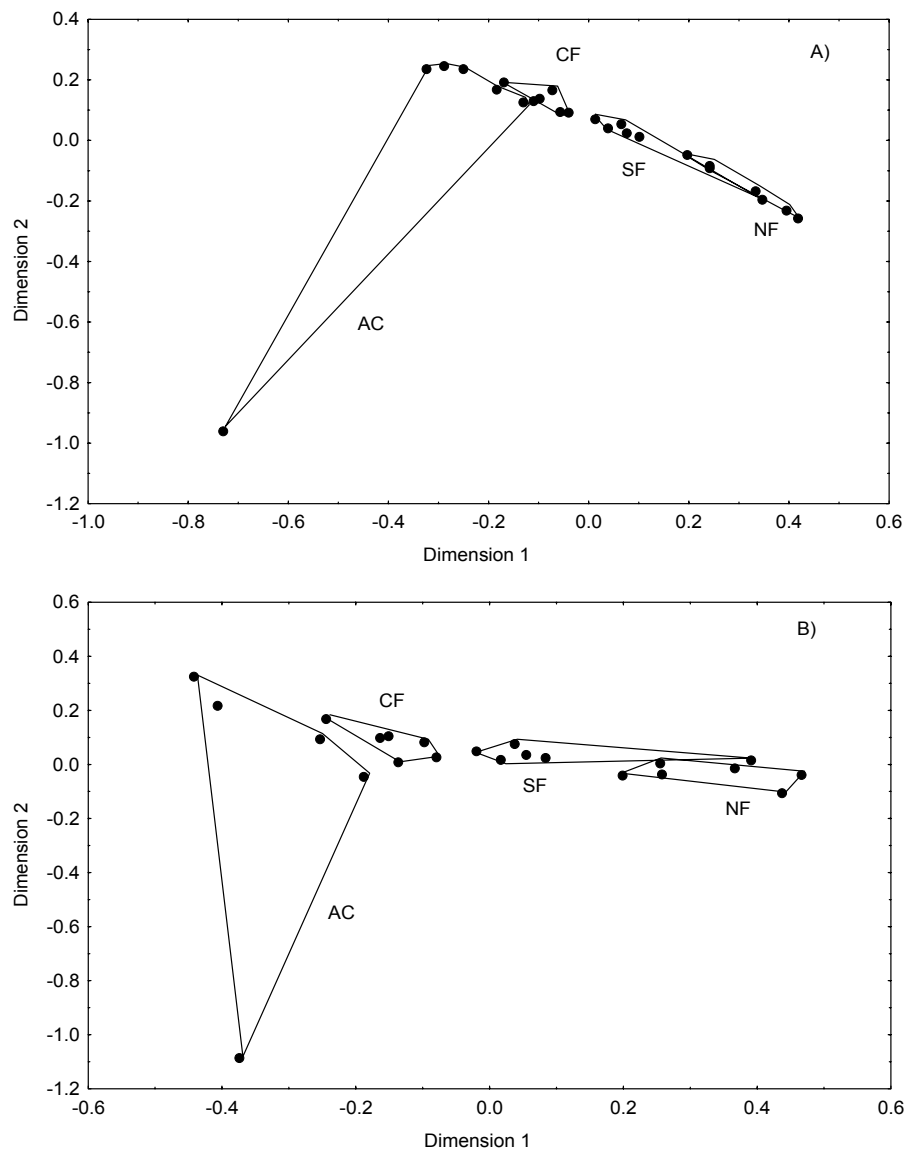


Figure V.3.: Correspondence analyses plot of understorey birds' similarity between different study sites based on abundance data. Study sites belonging to the same habitat category are

connected by lines. See Fig. V.1. for abbreviations of habitats. A) from original data; B) when most left sample in A) is removed from the analysis.

V.3.3. Species-level response

Out of the 93 species captured, 25 species showed significant responses to habitat type (ANOVAs, $P < 0.05$), i.e. just 26.9% of all species (see Appendix). After sequential Bonferroni corrections of the P significance value of this list, just five species showed significant responses to habitat type. Based on ANOVA and post hoc tests (Tukey's HSD test, $P < 0.05$), three main categories were defined. In category 1, the Pale-breasted Illadopsis *Illadopsis rufipennis* and Icterine Greenbul *Phyllastrephus icterinus* showed clear preference to near-primary forest with a significantly lower abundance in other habitats. In category 2, the Forest Robin *Stiphrornis erythrothorax* and Lesser Bristlebill *Bleda notata* showed clear preference to both natural habitats (NF and SF), with a significantly lower abundance in land use habitats (CF and AC). In category 3, the Little Greenbul *Andropadus virens* showed clear preference for land use habitats, with a significantly lower abundance in natural habitats (see Table V.3.). Twelve species (12.9%) were found using all four habitat types.

Table V.3.: Understorey bird species with significant responses to habitat type, after sequential Bonferroni correction.

Family	Species	<i>n</i>	<i>F</i> _{3,20}	<i>P</i>	Category	Habitat with highest abundance
Pycnonotidae	Little Greenbul	166	10.81	0.0002	3	CF, AC
	Icterine Greenbul	34	11.87	0.0001	1	NF
	Lesser Bristlebill	62	10.76	0.0002	2	NF, SF
Turdidae	Forest Robin	96	23.97	0.0000	2	NF, SF
Timaliidae	Pale-breasted Illadopsis	38	20.28	0.0000	1	NF

Notes: (*n*) total number of individuals of understorey birds captured; Results of One-way ANOVA (*F*), table wide-significance (*P*) as well as response categories and preferred habitat are given; See Fig. V.1. for abbreviations of habitats.

V.3.4. Understorey bird community structure

V.3.4.1. Overall abundance

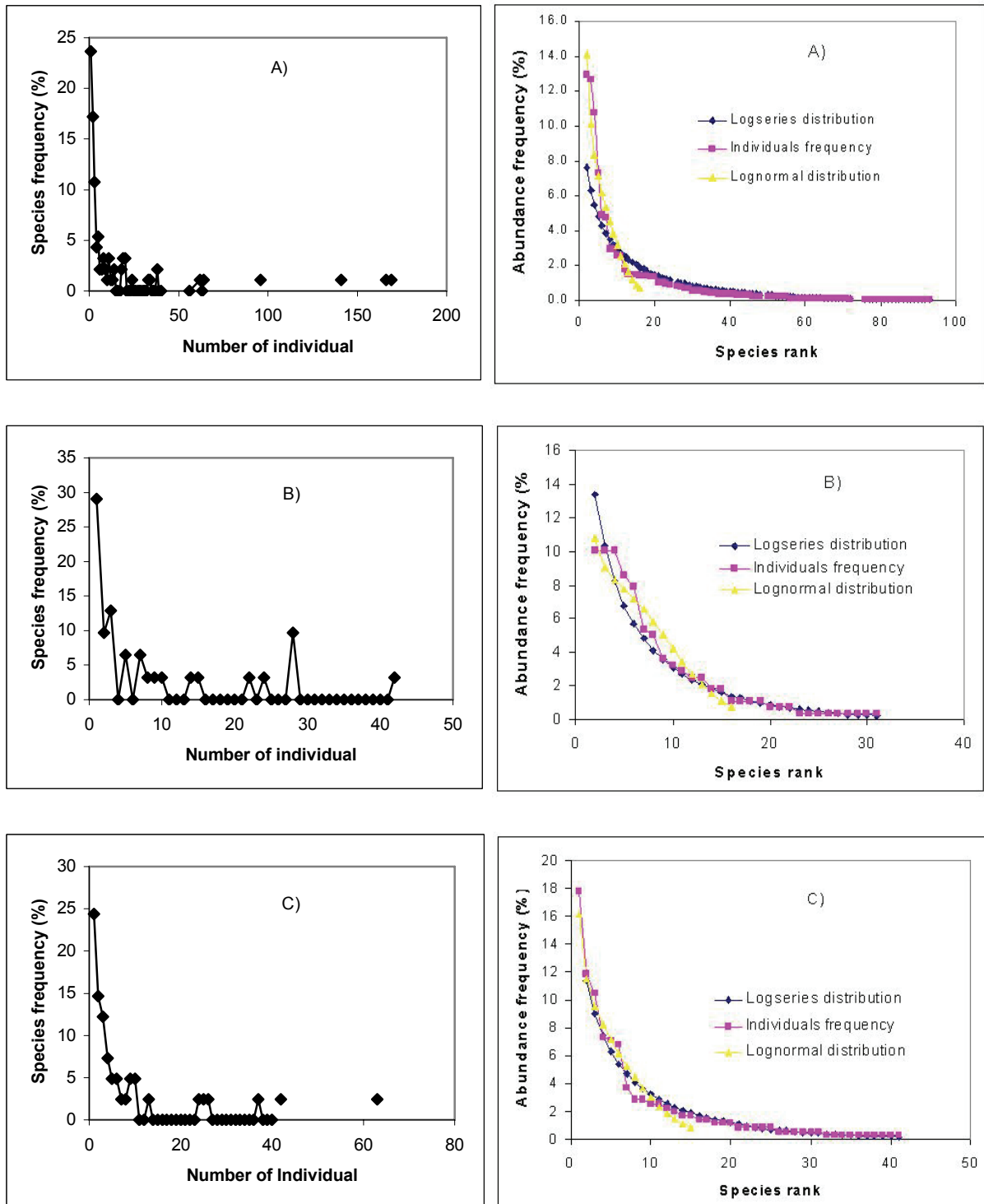
Mist-netting produced a total of 1,528 captures. The number of captures was not significantly affected by habitat type (one-way ANOVA, $F_{3,20} = 1.06$, $p = 0.39$): the number of captures per sampling station were highest in SF (70.5 ± 12.56 ; mean \pm SD), slightly lower in AC (66.7 ± 22.7) and CF (65.0 ± 21.2), and lowest in NF (52.5 ± 15.8).

The number of captures was very highly and positively correlated with the number of individuals (§ V.3.1.) ($r_s = 0.98$, $p < 0.001$); thus the pattern of captures number can be inferred to that of individual numbers.

V.3.4.2. Species abundance patterns

Species abundant patterns for all captured species did not differ from a (truncated) lognormal distribution (χ^2 Goodness of fit tests = 4.05, $p < 0.99$) nor from a logseries distribution (χ^2 Goodness of fit tests = 19.94, $p < 1.00$, see Fig. V.4A.). The four most abundant species, namely Olive Sunbird, Little Greenbul, Yellow-whiskered Greenbul and Forest Robin, were captured with more than 95 individuals (96 to 169) each. Fifty-two species, which accounted for less than five individuals, are classified as ‘rare’. Captured species abundance patterns in NF did not differ from a (truncated) lognormal (χ^2 Goodness of fit tests = 2.46, $p < 0.99$) nor from a logseries distribution (χ^2 Goodness of fit tests = 3.53, $p < 1.00$, see Fig. V.4B.). The five most abundant species in NF include Forest Robin, Pale-breasted Illadopsis, Lesser Bristlebill, Fire-crested Alethe and Olive Sunbird with respectively 42, 28, 28, 28 and 24 individuals. Sixteen species are classified as ‘rare’ in NF. In SF, abundance patterns fitted both to a (truncated) lognormal (χ^2 Goodness of fit tests = 2.42, $p < 1.00$) and a logseries distribution (χ^2 Goodness of fit tests = 3.25, $p < 0.99$, see Fig. V.4C.). The six most abundant species are Yellow-whiskered Greenbul, Olive sunbird, Forest Robin, Little Greenbul, Fire-crested Alethe and Lesser Bristlebill with respectively 63, 42, 37, 26, 25 and 24. Twenty-four species are considered as ‘rare’ in SF. Mist-netted species abundance patterns in CF did not differ from a (truncated) logseries (χ^2 Goodness of fit tests = 36.11, $p < 0.83$); but it differed significantly from a lognormal distribution (χ^2 Goodness of fit tests = 57.88, $p < 0.000$, see Fig. V.4D.). Three species appeared to be the most abundant in CF namely Little Greenbul, Olive Sunbird and Yellow-whiskered Greenbul with respectively 82, 71 and 50 individuals. Thirty-eight species are considered as ‘rare’ in CF. Captured species abundance patterns in

AC did not differ from a (truncated) lognormal (χ^2 Goodness of fit tests = 3.20, all $p < 0.99$) nor from a logseries distribution (χ^2 Goodness of fit tests = 1.79, all $p < 1.00$, see Fig. V.4E.). The three most abundant species in AC are Little Greenbul, Olive Sunbird and Olive-bellied Sunbird with respectively 56, 32 and 30 individuals. Thirty-one species are classified as ‘rare’ in AC.



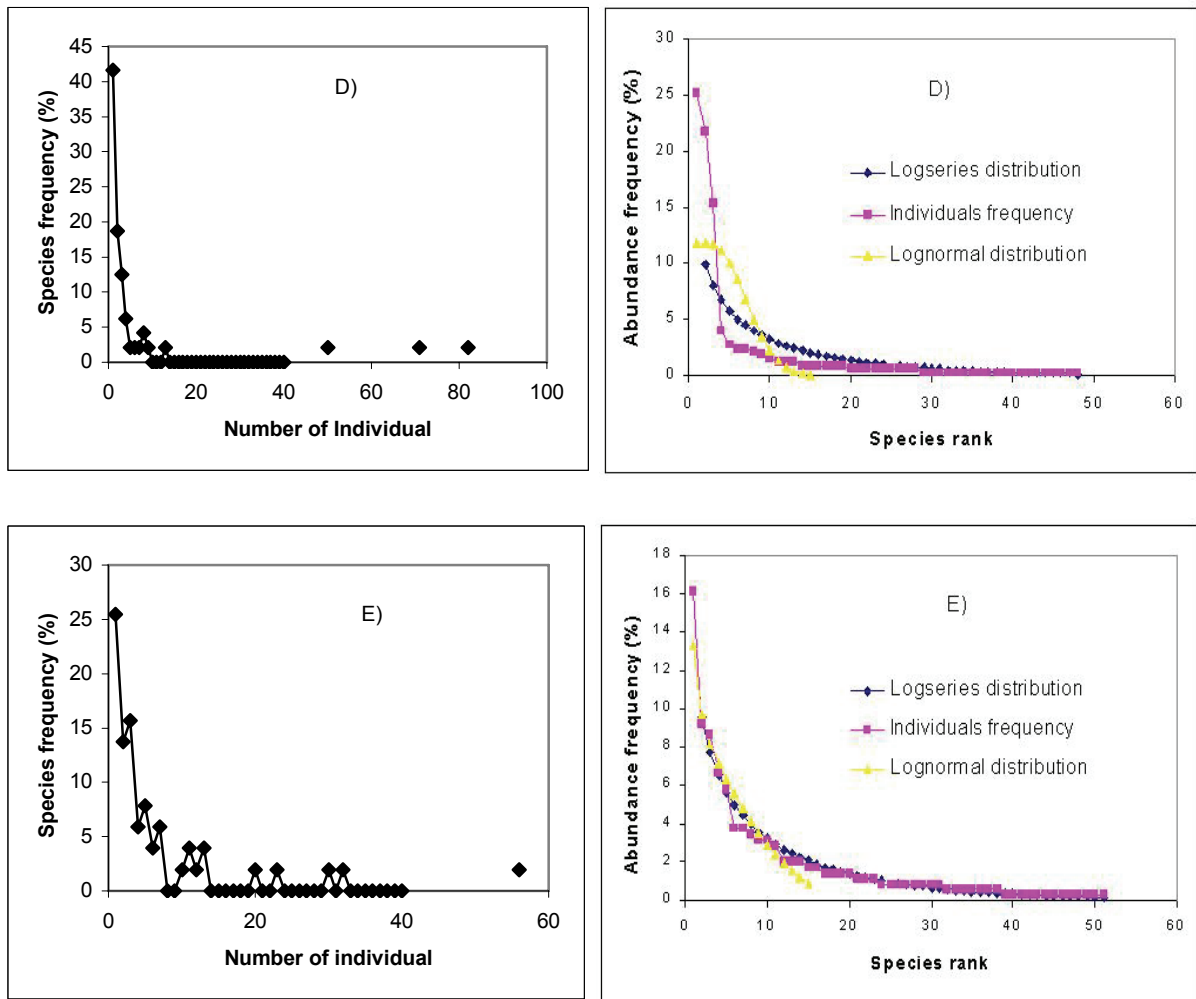


Figure V.4.: Species-abundance distribution and rank-abundance plots for A) all mist-netted species, B) species captured in NF, C) species captured in SF, D) species captured in CF and E) species captured in AC. Expected distributions (logseries and lognormal curves) are included to rank-abundance plots.

It should be noted that the overall number of ‘rare’ species increases from natural habitats (NF and SF) to land use systems (CF and AC) i.e. from 16 in NF and 24 in SF to 38 in CF and 31 in AC. Also, many true forest species captured in great numbers in natural habitats are considered ‘rare’ in land use systems (see Table V.4.), suggesting that some individuals of these species are using degraded habitats temporally for their daily needs, outside their territories known to be somewhere in the nearby natural forests.

Table V.4.: Comparison of true forest understorey species abundance from natural habitats to land use systems.

Species	Number of individuals			
	NF	SF	CF	AC
Blue-headed crested Flycatcher	10	9	1	0
Lesser Bristlebill	28	24	0	1
Pale-breasted Illadopsis	28	9	1	0
Icterine Greenbul	22	10	2	0
Fire-crested Alethe	28	25	8	3
Red-tailed Bristlebill	9	8	2	0
Forest Robin	42	37	13	4
Red-tailed Greenbul	3	13	3	1

Notes: See Fig. V.1. for abbreviations of habitats.

V.3.4.3. Family level

V.3.4.3.1. Overall

One thousand three hundred and seven (1307) individuals (recaptures are excluded) were mist-netted in all the four habitat types, belonging to 93 species from 24 families. The most abundant bird families were Pycnonotidae, Nectariniidae, Turdidae, Sylviidae, Estrildidae, Timaliidae, Monarchidae, Alcedinidae and Platysteiridae with respectively 503, 219, 208, 82, 80, 53, 34, 30 and 25 individuals. ‘Rare’ families include Strigidae, Malaconotidae, Eurylaimidae, Dicruridae, Bucerotidae, Motacillidae, Muscicapidae, Meropidae and Accipitridae with less than five individuals each (see Fig. V.5A.).

Pycnonotidae, Nectariniidae, Sylviidae and Turdidae also appeared to be the most species-rich families with respectively 15, 10, 9 and 7 species. Other species-rich families include Estrildidae (six species), Alcedinidae (five species), Indicatoridae, Platysteiridae and Ploceidae all represented by four species each. Capitonidae, Columbidae, Monarchidae, Muscicapidae and Timaliidae were all represented by three species each. Accipitridae, Cuculidae, Meropidae and Picidae were all represented by two species each. Bucerotidae, Dicruridae, Eurylaimidae, Malaconotidae, Motacillidae and Strigidae were all represented by one species each (see Fig. V.5B.).

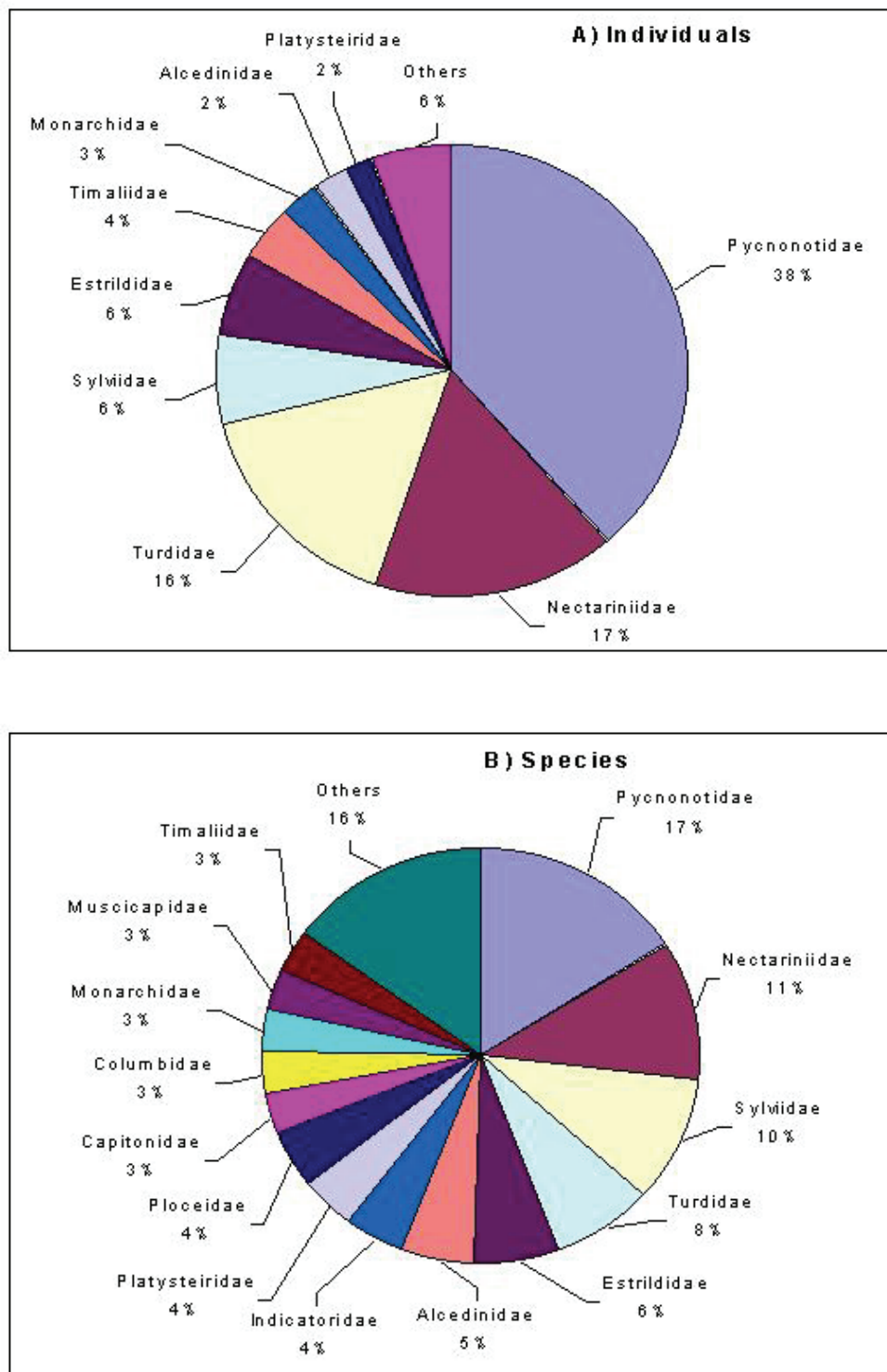


Figure V.5.: Percentages of (A) individuals (n= 1307) and (B) understorey bird species (n= 93) of different mist-netted families.

V.3.4.3.2. Comparison between habitats

A comparison of individual percentages for the six most abundant families revealed no clear overall defined pattern between the four habitat types (see Fig. V.6A.). It was not also clear for Pycnonotidae's proportion with 16.9% in NF, 30.4% in SF, 31.6% in CF and 21.1% in AC. However, trends were visible in some families: the proportion of Turdidae decreases with increasing habitat modifications from 44.2% in NF and 39.4% in SF to 12.0% in CF and 4.3% in AC; the same pattern was observed for Timaliidae, which tend to avoid disturbed habitats, with 66.0% in NF and 32.1% in SF to 1.9% in CF and 0.0% in AC. The proportion of Nectariniidae increases with increasing habitat modifications from 11.4% in NF and 20.1% in SF to 35.6% in CF and 32.9% in AC. The same pattern was observed for Sylviidae with 6.1% in NF and 12.2% in SF to 24.4% in CF and 57.3% in AC. The Estrildidae percentages indicated that individuals of this family tend to be confined to very degraded habitats with 67.5% in AC to 10.0% in CF, 12.5% in SF and 10.0% in NF (see Fig. V.6A.).

A comparison of species percentages for the six species-rich families revealed that overall number of species increases with increasing habitat modifications from 20 species in NF and 25 species in SF to 29 species in CF and 36 species in AC (see Fig. V.6B.). The species proportion of Pycnonotidae decreases with increasing habitat modifications from 40.0% (8 species) in NF and 40.0% (10 species) in SF to 31.0% (9 species) in CF and 25.0% (9 species) in AC. Similar pattern was observed for Turdidae with a species proportion of 20.0% (4 species) in NF and 24.0% (6 species) in SF to 13.8% (4 species) in CF and 11.1% (4 species) in AC. The species proportion of Nectariniidae increases with increasing habitat modifications from 10.0% (2 species) in NF and 8.0% (2 species) in SF to 17.2% (5 species) in CF and 22.2% (8 species) in AC. Similar pattern was observed for Sylviidae with a species proportion of 15.0% (3 species) in NF and 12.0% (3 species) in SF to 20.7% (6 species) in CF and 19.4% (7 species) in AC (see Fig. V.6B.).

The overall numbers of captures as well as the numbers of individuals were significantly different between habitat types in six families (see above). Both parameters were also highly and positively correlated (see § V.3.4.1.). Estrildidae (six species in total) were significantly more abundant in AC than in other habitat types (one-way ANOVA, $F_{3, 20} = 3.60$, $p < 0.03$ for individuals). The abundance of Nectariniidae (ten species in total) was significantly higher in AC and CF, and relatively lower in SF, than in NF (one-way ANOVA, $F_{3, 20} = 7.35$, $p < 0.0016$ for individuals).

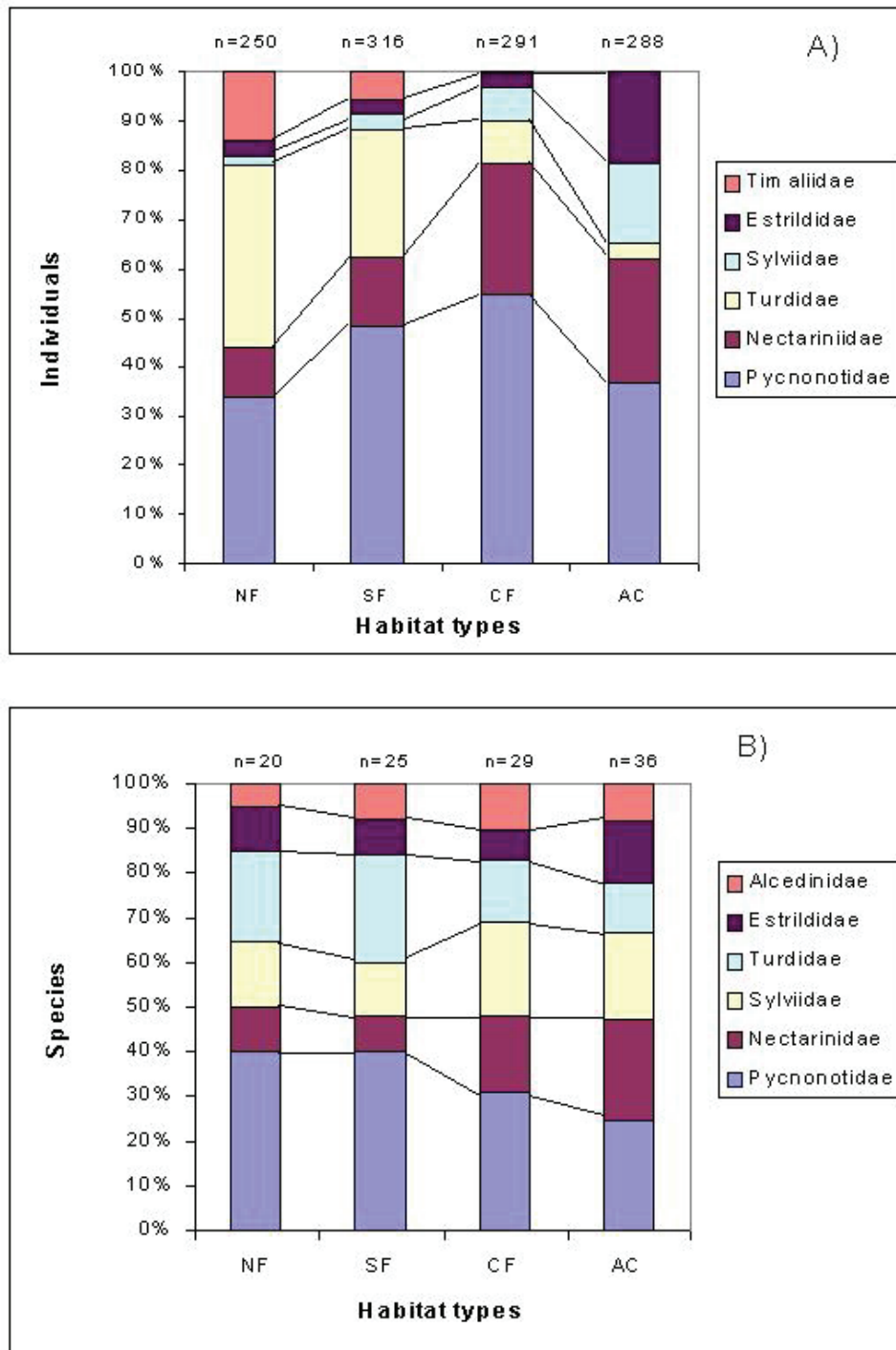


Figure V.6.: Percentage of (A) individuals and (B) species of well-represented understory bird families captured in the four habitat types.

Ploceidae (four species in total) were significantly more abundant in land use systems (AC and CF) than in natural habitats (SF and NF) (one-way ANOVA, $F_{3, 20} = 3.88$, $p < 0.02$ for individuals). In Sylviidae (nine species in total), highest abundance was found in AC; it was significantly different in other habitat types (one-way ANOVA, $F_{3, 20} = 11.43$, $p < 0.001$ for

individuals). Timaliidae (three species in total) showed significantly higher abundance in NF as compared to other habitat types (one-way ANOVA, $F_{3, 20} = 17.88$, $p < 0.001$ for individuals). The abundance of Turdidae (seven species in total) decreases with increasing habitat modifications: it was significantly higher in natural habitats (NF and SF) than in land use systems (CF and NF) (one-way ANOVA, $F_{3, 20} = 28.64$, $p < 0.001$ for individuals). All other families present in considerable numbers, namely Pycnonotidae, Monarchidae, Alcedinidae and Platysteiridae, were relatively equally abundant in the four habitat types.

V.3.4.4. Specie level

Out of the 93 species captured, twenty-five species showed significant responses to habitat type (ANOVAs, $P < 0.05$), i.e. just 26.9% of all species (see Appendix V.1.).

V.3.4.4.1. Species found in all habitat types

Out of the 93 species captured, twelve (i.e. 12.9%) were found using all four habitat types among which eight were insectivorous (White-bellied kingfisher *Alcedo leucogaster*, Lesser Bristlebill *Bleda notata*, Red-tailed Greenbul *Criniger calurus*, Forest Robin *Stiphrornis erythrothorax*, Fire-crested Alethe *Alethe diademata*, White-tailed Ant-Thrush *Neocossyphus poensis*, Green Hylia *Hylia prasina*, Red-bellied paradise Flycatcher *Terpsiphone rufiventer*), two omnivorous (Little Greenbul *Andropadus virens*, Yellow-whiskered Greenbul *A. latirostris*), one Nectariniidae (Olive Sunbird *Cyanomitra obscura*) and one granivorous (Western Bluebill *Spermophaga haematina*) (see Appendix V.1.).

V.3.4.4.2. Species unaffected by habitat modifications

Among the twelve species captured in all habitat types, four, all insectivorous birds (White-bellied kingfisher *Alcedo leucogaster*, Fire-crested Alethe *Alethe diademata*, White-tailed Ant-Thrush *Neocossyphus poensis*, Green Hylia *Hylia prasina*) did not show significant differences in abundance between habitat types (One-way ANOVA, for all the four species, $p > 0.1$) (see Appendix V.1.).

V.3.4.4.3. Species with significantly higher abundance in land use systems

Among the 25 understorey bird species with significant responses to habitat type, one granivorous (Blue-spotted Wood-dove *Turfur afer*), nine insectivorous (African Pigmy Kingfisher *Ceyx pictus*, Little grey Greenbul *Andropadus gracilis*, Baumann's Greenbul *Phyllastrephus baumanni*, Western Nicator *Nicator chloris*, Red-tailed Greenbul *Criniger calurus*, Chattering Cisticola *Cisticola anonymus*, Grey-backed Camaroptera *Camaroptera brachyura*, Green Crombec *Sylvietta virens*, Black-necked Weaver *Ploceus nigricollis*), two omnivorous (Speckled Thinkerbird *Pogoniulus scolopaceus*, Little Greenbul *Andropadus virens*), two Nectariniidae (Collared Sunbird *Hedydipna collaris*, Olive-bellied Sunbird *Cynniris chloropygius*) and one granivorous (Western Bluebill *Spermophaga haematina*) showed significantly higher abundance in land use systems (CF and/or AC) as compared to natural habitats (NF and SF) (see Appendix V.1.).

V.3.4.4.4. Species with significantly higher abundance in natural habitats

Among the 25 understorey bird species with significant responses to habitat type, only insectivorous birds, eight species, (Icterine Greenbul *Phyllastrephus icterinus*, Xavier's Greenbul *P. xavieri*, Lesser Bristlebill *Bleda notata*, Forest Robin *Stiphrornis erythrothorax*, Brown-chested Alethe *Alethe poliocephala*, Yellow-bellied Wattle-eye *Dyaphorophya concreta*, Pale-breasted Illadopsis *Illadopsis rufipennis*, Blackcap Illadopsis *I. cleaveri*) showed significantly higher abundance in natural habitats (NF and/or SF) as compared to land use systems (CF and/or AC) (see Appendix V.1.).

V.3.4.4.5. Species with significantly higher abundance in SF and CF

Among the 25 understorey bird species with significant responses to habitat type, one omnivorous (Yellow-whiskered Greenbul *A. latirostris*) and one Nectariniidae (Olive Sunbird *Cyanomitra obscura*) showed significantly higher abundance in secondary forest and agroforestry systems (see Appendix V.1.).

V.3.4.4.6. Species uniquely captured in NF

Among the eight understorey insectivorous bird species with significantly higher abundance in natural habitats, one (Yellow-bellied Wattle-eye *Dyaphorophya concreta*) was found only in near-primary forest (see Appendix V.1.).

V.3.4.4.7. Species uniquely captured in AC

Among the 15 understorey bird species with significantly higher abundance in land use systems, four insectivorous (Baumann's Greenbul *Phyllastrephus baumanni*, Chattering Cisticola *Cisticola anonymus*, Green Crombec *Sylvietta virens*, Black-necked Weaver *Ploceus nigricollis*), one granivorous (Blue-spotted Wood-dove *Turkey afer*) and one Nectariniidae (Collared Sunbird *Hedydipna collaris*) were found only in annual cultures (see Appendix V.1.).

V.3.4.4.8. Species absent only in NF

Among the 25 understorey bird species with significant responses to habitat type, one insectivorous (Grey-backed Camaroptera *Camaroptera brachyura*) was found in all habitat types except near-primary forest, suggesting that this species tends to avoid pristine habitats (see Appendix V.1.).

V.3.5. Habitat preference and geographic range

Geographic ranges of the captures are defined as 1: Western West Africa to Southwestern Cameroon or from Southwestern Cameroon to Gabon-Congo-CAR zone, 2: Western West Africa to Gabon-Congo-CAR zone or Southeastern Nigeria to East of Rift Valley, 3: Western West Africa to East of Rift Valley and 4: Throughout Africa in suitable habitats.

Among the 93 understorey bird species captured, 11 are either confined to the region between the western West Africa to the southwestern Cameroon or between the southwestern Cameroon to the Gabon-Congo-CAR zone; 13 are confined to the region between the western West Africa to the Gabon-Congo-CAR zone or between the southeastern Nigeria to East of Rift Valley; 58 are confined to the region between the western West Africa to the East of Rift Valley; and 11 are found throughout Africa in suitable habitats.

Defining each species association with the near-primary forest as the proportion of captures there, a weak but significant, negative relationship between the extent of the species' geographic range and their habitat preference was found (Gamma rank correlation for multiple ties, $\gamma = -0.304$, $p = 0.019$, $N = 93$ spp., see Fig. V.7A.). Including only species with a minimum of six captures reduces the number of species in the analysis to 37; the relationship is still weak and negative, but insignificant (Gamma rank correlation for multiple ties, $\gamma = -0.257$, $p = 0.109$, $N = 37$ spp., see Fig. V.7A').).

The species association with the secondary forest showed a weak but significant, negative relationship between the extent of the species' geographic range and their habitat preference (Gamma rank correlation for multiple ties, $\gamma = -0.354$, $p = 0.0019$, $N = 93$ spp., see Fig. V.7B.). The relationship becomes insignificant when only species with a minimum of six captures were considered in the analysis (Gamma rank correlation for multiple ties, $\gamma = -0.255$, $p = 0.108$, $N = 37$ spp., see Fig. V.7B').).

The species association with agroforestry systems showed an almost null and insignificant, negative relationship between the extent of the species' geographic range and their habitat preference (Gamma rank correlation for multiple ties, $\gamma = -0.052$, $p = 0.637$, $N = 93$ spp., see Fig. V.7C.). The relationship is still insignificant when only species with a minimum of six captures were considered in the analysis (Gamma rank correlation for multiple ties, $\gamma = -0.133$, $p = 0.384$, $N = 37$ spp., see Fig. V.7C').).

The species association with annual crop farms showed a weak and just significant, but positive relationship between the extent of the species' geographic range and their habitat preference (Gamma rank correlation for multiple ties, $\gamma = 0.209$, $p = 0.049$, $N = 93$ spp., see Fig. V.7D.). The relationship becomes insignificant when only species with a minimum of six captures were considered in the analysis (Gamma rank correlation for multiple ties, $\gamma = 0.136$, $p = 0.368$, $N = 37$ spp., see Fig. V.7D').).

Thus, understorey bird species with a smaller geographic range showed a preference for near-primary forest where as those with a larger geographic range prefer more disturbed habitats.

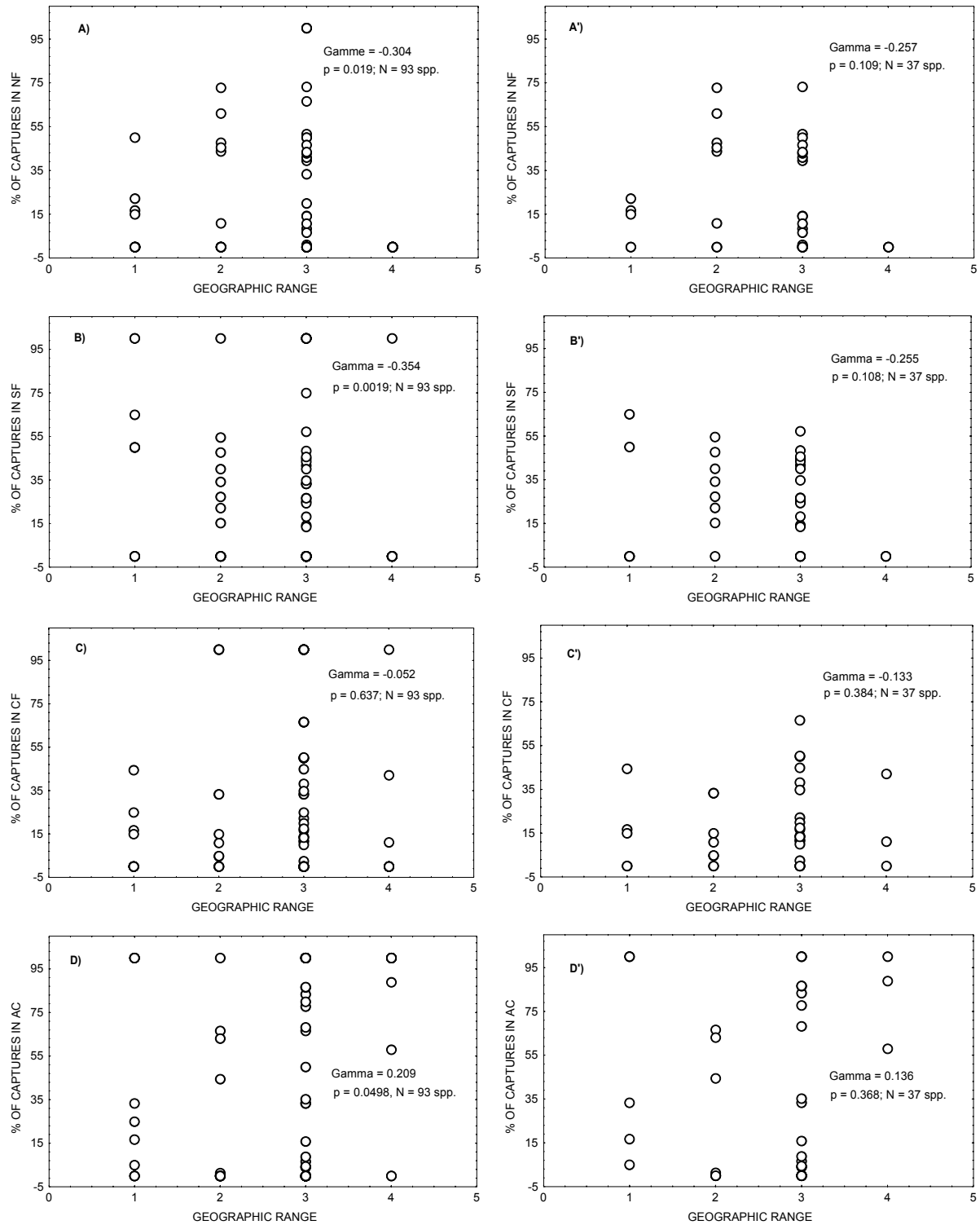


Figure V.7.: Relationship between geographic distribution and habitat preference in 93 understorey bird species from mist-net samples in A) NF, B) SF, C) CF and D) AC. Beside are the relationship when only species with a minimum of six captures were considered in the analysis (i.e. 37 species) in A') NF, B') SF, C') CF and D') AC. The Gamma rank correlation coefficient (γ) and the significance level are included. See Fig. V.1. for abbreviations of habitats.

V.3.6. Habitat preference and body mass

Body mass is the most frequently used index of body size in ornithological literature. In this study, mist-netted species were both Non-passeriformes ranging in mean body from 9 g (African Dwarf Kingfisher *Ceyx lecontei*) to 717 g (White-thighed Hornbill *Bycanistes albotibialis*) and, Passeriformes ranging in mean body weight from 5 g (Little green Sunbird *Antheptes seimundi*) to 50.35 g (White-tailed Ant Thrush *Neocossyphus poensis*). The interspecific comparisons of the 93 mist-netted species indicated very weak and insignificant correlations between body size and preference respectively for near-primary forest (Spearman $R = 0.021$, $t(N-2) = 0.203$, $p = 0.839$), secondary forest (Spearman $R = 0.036$, $t(N-2) = 0.343$, $p = 0.732$), agroforestry system (Spearman $R = -0.079$, $t(N-2) = -0.752$, $p = 0.454$) and annual cultures (Spearman $R = -0.107$, $t(N-2) = -1.023$, $p = 0.309$).

Considering just species with a minimum number of six captures, almost all, except Blue-spotted Wood-dove *Turtur afer* (58.56 g), African Pigmy Kingfisher *Ceyx pictus* (11.11 g), White-bellied Kingfisher *Alcedo leucogaster* (16.2 g) and Speckled Thinkerbird *Pogoniulus scolopaceus* (15.11 g) which are Non-passeriformes, were Passeriformes ranging in mean body weight from 6.14 g (Olive-bellied Sunbird *Cinnyris chloropygius*) to 50.35 g (White-tailed Ant Thrush *Neocossyphus poensis*). Many species with considerably higher capture rates in annual crop farms were small understorey insectivores such as Warblers and Estrildidae (see Appendix V.1.). In contrast, most species preferring the near-primary forest were medium to large-sized insectivorous Thrushes and Picnonotids species such as Brown-chested Alethe *Alethe poliocephala*, White-tailed Ant Thrush *Neocossyphus poensis*, Icterine Greenbul *Phyllastrephus icterinus*, Red-tailed Greenbul *Criniger calurus*, Lesser Bristlebill *Bleda notata* (see Appendix V.1.). Consequently, an interspecific comparison of the 37 species with at least six captures, indicated a modest, significantly positive correlation between body mass and preference for near-primary forest (Spearman $R = 0.355$, $t(N-2) = 2.243$, $p = 0.031$, see Fig. V.8A.). A weak and insignificant correlation was found between body mass and preference for secondary forest (Spearman $R = 0.266$, $t(N-2) = 1.630$, $p = 0.112$, see Fig. V.8B.). A weak and insignificant correlation was also found between body mass and preference for agroforestry systems (Spearman $R = -0.215$, $t(N-2) = -1.304$, $p = 0.201$, see Fig. V.8C.). A weak and insignificant correlation was also found between body mass and preference for annual croplands (Spearman $R = -0.224$, $t(N-2) = -1.361$, $p = 0.182$, see Fig. V.8D.).

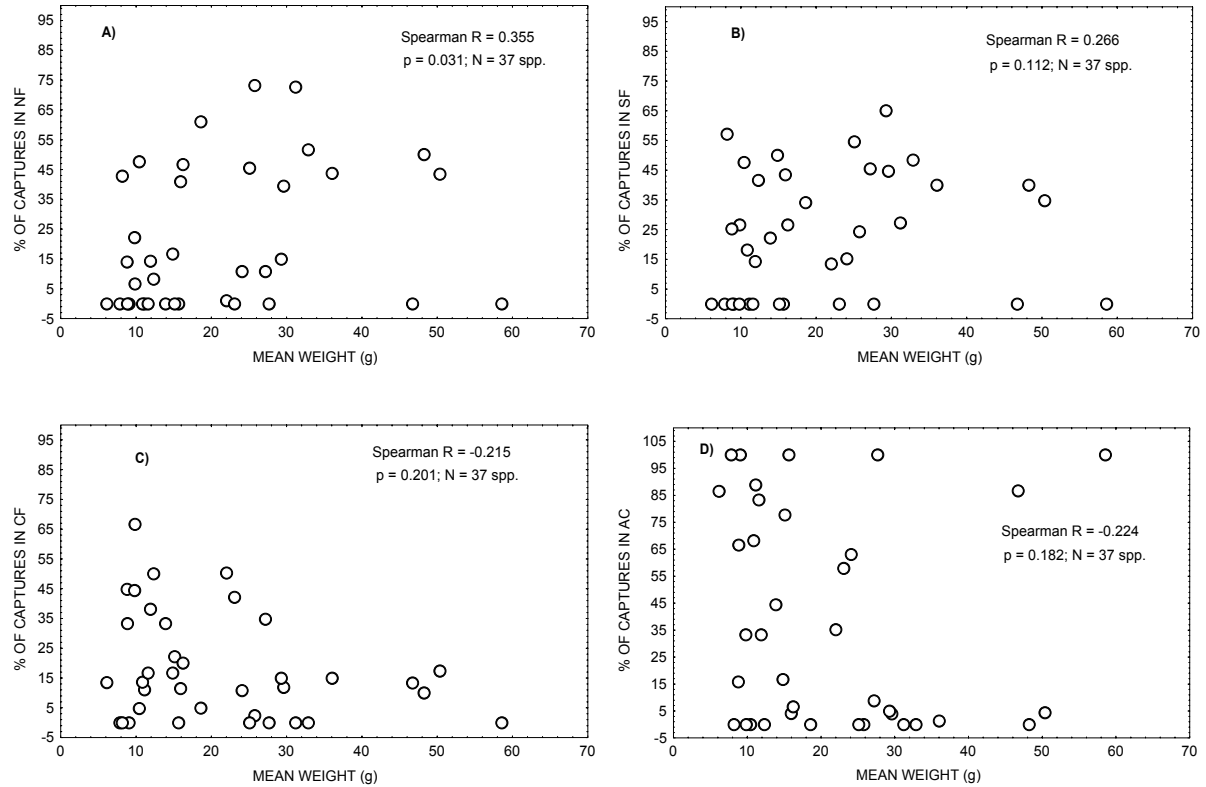


Figure V.8.: Relationship between body mass and habitat preference in 37 understorey bird species with a minimum of six captures from mist-net samples in A) NF, B) SF, C) CF and D) AC. The Spearman rank correlation coefficient (R) and the significance level are included. See Fig. V.1. for abbreviations of habitats.

V.3.7. Habitat preference and vertical foraging niches

Among the 93 species mist-netted, 18 species are usually found higher up than 20 m, i.e. at canopy level (“Upperstorey”), 43 species are known to occupy the lowermost strata (“Understorey”) of forests between 0 and 5 m height, and 32 species are usually found between 5 and 20 m (“Midstorey”) (see Borrow and Demey 2001).

In an interspecific comparison of all the 93 species mist-netted, a very weak and insignificant, positive correlation was found between average foraging height and relative preference for near-primary forest (Gamma rank correlation for multiple ties, $\gamma = 0.113$, $p = 0.349$, see Fig. V.9A.). An almost null and insignificant, positive correlation was found between average foraging height and relative preference for secondary forest (Gamma rank correlation for multiple ties, $\gamma = 0.021$, $p = 0.843$, see Fig. V.9B.). A very weak and insignificant, negative correlation was also found between average foraging height and relative preference for

agroforestry systems (Gamma rank correlation for multiple ties, $\gamma = -0.156$, $p = 0.126$, see Fig. V.9C.). But, a weak and significant, positive correlation was found between average foraging height and relative preference for annual cropland (Gamma rank correlation for multiple ties, $\gamma = 0.223$, $p = 0.033$, see Fig. V.9D.). Thus, species usually found at canopy level were more easily trapped in AC, whereas species from the understorey layer were more easily trapped in NF.

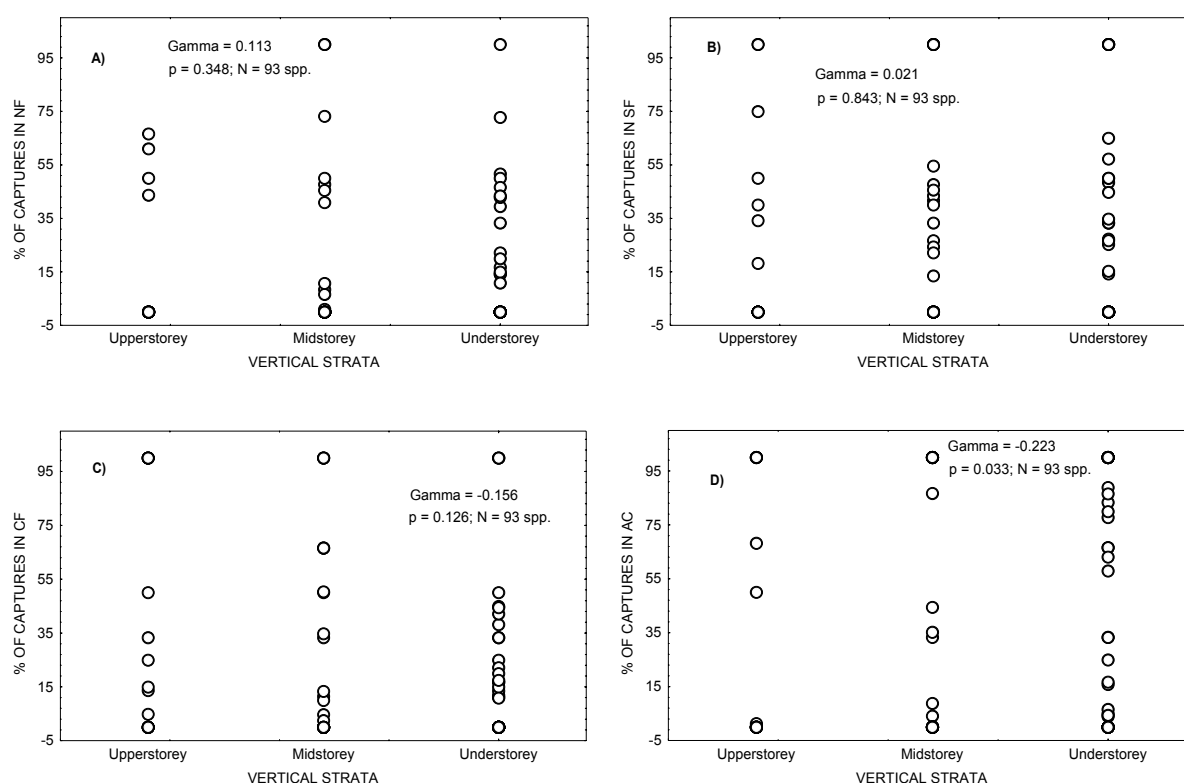


Figure V.9.: Relationship between vertical foraging height and habitat preference in 93 understory bird species from mist-net samples in A) NF, B) SF, C) CF and D) AC. The Gamma rank correlation coefficient (γ) and the significance level are included. See Fig. V.1. for abbreviations of habitats.

V.3.8. Habitat preference and feeding guilds

The mist-netted community constituted of 93 species was largely dominated by Insectivores (62 species or 66.7%). Then followed Nectarivores (9 species or 9.7%), Granivores (8 species or 8.6%, constituted of Columbidae and Estrildidae), Omnivores (6 species or 6.5%), Frugivores (5 species or 5.4%) and Carnivores (3 species or 3.2%) (see Fig. V.10A.).

Most captures were obtained for the 62 Insectivorous species (51.2%). Captures of Omnivorous, Nectarivorous and Granivorous species represented 23.6%, 17.5% and 6.3% respectively. Captures of Frugivorous and Carnivorous species were by far less considerable, with respectively 1.1 and 0.3% (See Fig. V.10B.).

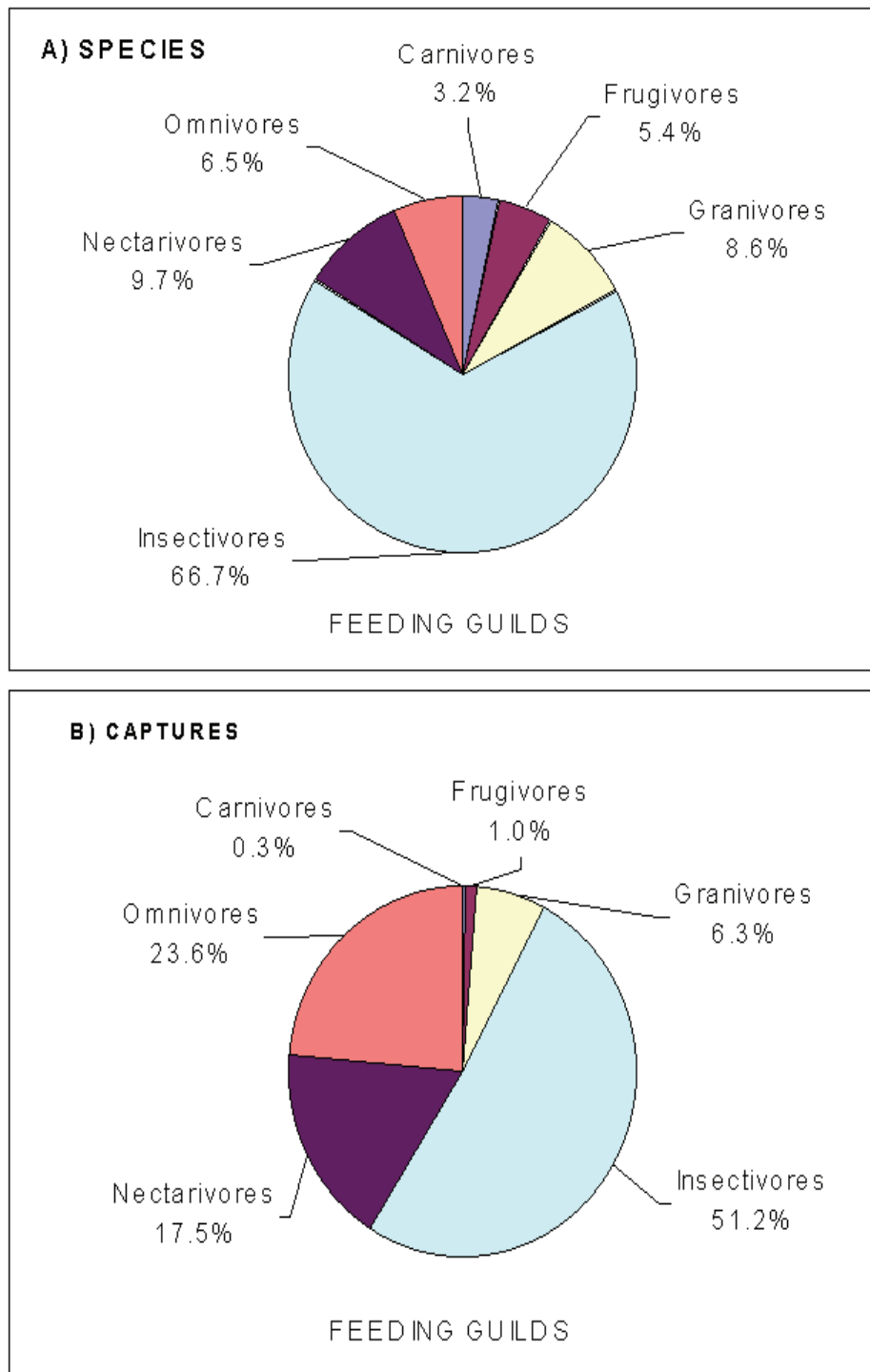


Figure V.10.: Feeding guild composition according to numbers of (A) species and (B) captures of the understory bird community.

The proportions of captures from different feeding guilds did not differ significantly among habitat types (Chi-sq. test, $\chi^2 = 4.95$, $p_{5df} = 0.422$). Captures of Carnivores were not significantly different between habitat types (Chi-sq. test, $\chi^2 = 6.82$, $p_{3df} = 0.078$). Captures of Frugivores were nearly significantly different between habitat types (Chi-sq. test, $\chi^2 = 7.22$, $p_{3df} = 0.065$). Captures of Granivores were significantly higher in annual cultures as compared to other habitat types (Chi-sq. test, $\chi^2 = 18.00$, $p_{3df} = 0.0004$). Captures of Insectivores were significantly higher in natural habitats as compared to land use types (Chi-sq. test, $\chi^2 = 10.67$, $p_{3df} = 0.014$). Captures of Nectarivores did not differ significantly between habitat types (Chi-sq. test, $\chi^2 = 6.00$, $p_{3df} = 0.112$). Captures of Omnivores in agroforestry systems differ significantly as compared to other habitat types (Chi-sq. test, $\chi^2 = 9.33$, $p_{3df} = 0.025$) (see Table V.5.).

Table V.5.: Number of captures of understorey birds of different feeding guilds in different habitat types.

	Habitat				All captures
	NF	SF	CF	AC	
Carnivores	3	0	2	0	5
Frugivores	0	4	5	7	16
Granivores***	5	7	12	72	96
Insectivores*	257	257	113	156	783
Nectarivores	30	56	105	76	267
Omnivores*	20	99	153	89	361
All captures	315	423	390	400	1528

Notes: Significant differences between habitats are marked with asterics (Chi-sq. test, $df = 3$, * for $p < 0.05$, *** for $p < 0.001$). See Fig. V.1. for abbreviations of habitats.

V.3.9. Comparison of the overall species richness pattern between the call-based and mist-netting methods

Based on observed species richness, results from the two methods differed significantly (Wilcoxon-test for equal cases: $Z_{24} = 4.29$, $P < 0.001$). A weak negative and insignificant correlation was found between the two sets of data (Gamma rank correlation for multiple ties, $\gamma = -0.260$, $p = 0.093$): With the call-based methods, overall observed species richness per

sampling station did not differ between habitat types (One-way ANOVA, $F_{3,20} = 2.21$, $p = 0.118$) and the pattern decreased with increasing habitat modification (see Fig. V.11., see also details in Waltert *et al.* 2005b). Mist-net overall observed species richness per sampling station was significantly affected by habitat types (On-way ANOVA, $F_{3,20} = 3.40$, $p = 0.038$), and no clear defined was found, but highest species richness was found in AC and lowest in NF (see Fig. V.11. and §.V.3.1.).

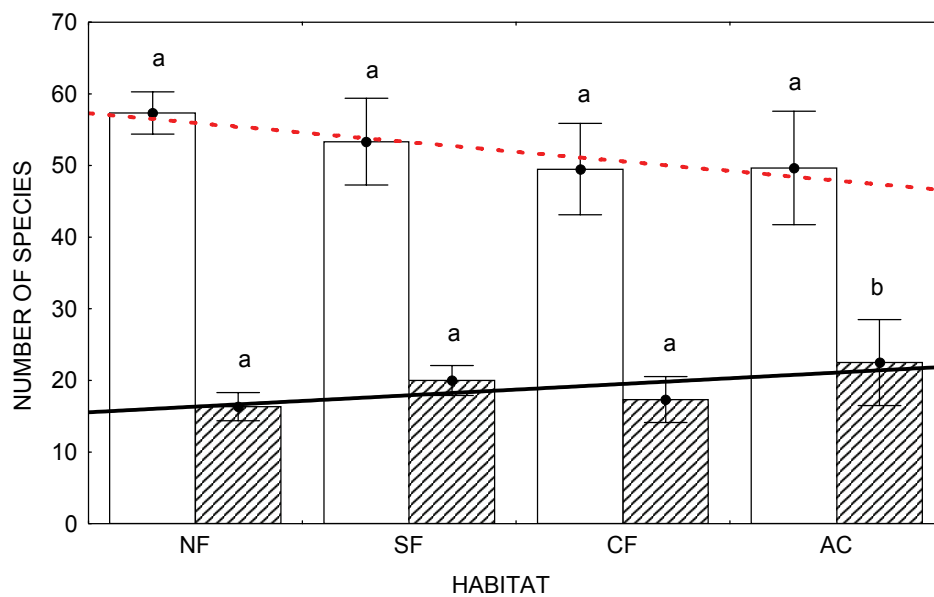


Figure V.11.: Comparison of the observed species richness patterns between the call-based (opened boxes) and the mist-netting (shaded boxes) methods. Points represent means. Error bars are Standard Deviation. Both lines represent linear relationship from NF to AC for both cases respectively. See Fig. V.1. for abbreviations of habitats.

V.4. Discussions

V.4.1. General notes on bird community studies

In the Lower Guinea rainforest, bird community structure had been already described in some detail for the Northeastern part of Gabon within the Cameroon-Gabon lowland rainforest region (Brosset & Erard 1986, Erard 1989, Brosset 1990). The present study in the Southwestern part of Cameroon is a first of such kind. In the Upper Guinean rainforest belt, detailed descriptions of the organisation of forest bird communities were made recently (Waltert 2000a), after first comprehensive surveys carried out some times ago, when large

parts of the original forest cover had already been destroyed (e.g. Thiollay 1985, Colston & Curry-Lindahl 1986, Allport *et al.* 1989, Gartshore *et al.* 1995). In other tropical regions, comprehensive documentation on the structure of forest bird communities from single sites is available (e.g. Robinson *et al.* 1990, Terborgh *et al.* 1990, Thiollay 1994 for Amazonia, Beehler 1981 and Bell 1982 for New Guinea).

V.4.2. Overall understorey bird species richness and abundance

Contrary to our hypothesis, although no significant difference was found in overall understorey bird abundance between habitat types, overall lowest numbers of individuals were captured in near-primary forest as compared to modified habitats. Similar patterns were already described for the western West African region when data from heavily logged forests in Eastern Côte d'Ivoire (Waltert 2000a,b) are compared to unlogged primary forests in Sierra Leone (Allport *et al.* 1989) and also within forest areas, the number of individuals captured can be significantly higher in disturbed than in undisturbed forest compartments (Waltert 2000a,b). In Southeast Asia, forest modification did not show any negative impact on overall abundance of understorey birds either (Waltert *et al.* 2005a).

Opposite to our prediction, overall understorey bird species richness, even when most abundant species are excluded, was higher in land use systems than in natural habitats: in fact we found an increase of species richness with increasing habitat modifications and all diversity indices were higher in annual cultures or land use systems than in natural habitats. The abundance of understorey plants used as principal habitat by understorey birds in land use systems might explain this result (read Bobo *et al.* 2006a). Similar results were found in Bossematié Forest Eastern Côte d'Ivoire where species richness and diversity of understorey birds on a small scale (2 - 8 ha) were higher in the disturbed than in the control compartment, and were attributed to the occurrence of "tourists" in the sample, i.e. species that were occasionally captured in the disturbed compartment due to shifting vertical foraging niches to lower levels that can be explained by the foraging behaviour of many midstorey and canopy species which follow the contour line of the canopy reaching ground level in gaps and along logging roads or to the timing of the mist-net censuses, which were carried out during and after the main breeding season, where many young birds still accompanied adults (Waltert 2000a,b). In the Gola forest in Sierra Leone, logged forest was richer than unlogged primary forest as far as Fisher's α and Simpson diversity indices are concerned (Allport *et al.* 1989).

This pattern has also been reported for other bird studies (Andrade & Rubio-Torgler 1994, Alvard & Winarni 1999) and for butterflies (Hill *et al.* 1995, Brown 1997, Wood & Gillman 1998, Fermon *et al.* 2000). But in the Malaysian rain forest, bird species richness and individual abundance were lower in the regenerating forest understory than in the virgin forest (Wong 1986). When using the call-based method on the same plots in the Korup region: insignificantly highest species richness was found in near-primary forest, which was slowly decreasing with increasing habitat modifications (Waltert *et al.* 2005b). This result was attributed to the relatively high tree species richness and abundance in the agricultural matrix, and also the small distance to the forest habitats (Waltert *et al.* 2005b, see also Daily *et al.* 2001, Greenberg *et al.* 1997b). In studies where only very few trees were present in the agricultural land, a marked decrease in richness was found from forest to land use systems (Lawton *et al.* 1998, Waltert *et al.* 2004, Schulze *et al.* 2004).

Apart from the mist-netted bird community found in agroforestry systems that differed significantly from a lognormal distribution, overall as well as communities from near-primary forest, secondary forest and annual cultures did not differ significantly either from a lognormal distribution or from a logseries distribution and, the number 'rare' species was higher in disturbed than in natural habitat with a highest value in agroforestry systems, confirming earlier findings of the elevated number of rare species to be responsible for the good fit of a log-series distribution, generally believed to be an indicator for disturbed communities (Magurran 1988, Johns 1992, Herremans 1995, Waltert 2000a). In contrary, the situation of the mist-netted community in the Bossématié Forest in Eastern Côte d'Ivoire showed a substantially higher number of 'rare' species in control than in disturbed compartment, but almost similarly, all abundance patterns fitted both a (truncated) lognormal and a logseries distribution (see Waltert 2000a).

V.4.3. Insectivorous birds

With the call-based method, species richness of insectivorous birds showed a steady decreasing pattern with increasing habitat modifications; natural habitats being significantly richer than land use habitats (Waltert *et al.* 2005b), confirming that this group is considered vulnerable to deforestation and land use (see also Thiollay 1995, Plumptre 1997, Waltert *et al.* 2004) and tend to avoid forest edges (Thiollay 1999). Mist-net data on the same plots revealed that the number of captures of this group was significantly higher in natural habitats than in

land use habitats, but near-primary forest showed the lowest species richness and diversity indices than modified habitats.

V.4.4. Ant-followers

We found almost no difference between habitats in species richness of ant-following birds, but secondary forest seemed to be the richest and annual cultures the poorest as far as observed, Jackknife species richness and Shannon-Weiner diversity are concerned. With the call-based method, the land use types were found to be very poor in ant-following birds compared to natural habitats (Waltert *et al.* 2005b). These two similar results using two different recording methods clearly confirm that this group tends to avoid significantly modified habitats where frequent cutting and moving in land use prevent stable ecological conditions at ground level and produce an unstable supply of arthropod and other food resources such as small reptiles and frogs (Waltert *et al.* 2005b, see also Perfecto & Snelling 1995).

V.4.5. Omnivorous

Almost no difference between habitats in species richness of omnivorous and no clear trend were found with mist-net data. No clear defined pattern was also found with the number of captures although agroforestry systems showed a significantly higher value. Similar results were obtained with the call-based method (Waltert *et al.* 2005b). These two similar results using two different methods confirm that this group tends to avoid natural habitats where the variety of its food resources might be fewer, in contrast to ant-followers (see above), or this group is less sensitive to habitat modifications.

V.4.6. Nectarivorous

Steady increasing patterns were found in species richness and diversity of nectarivorous birds from near-primary forest to annual cultures as the availability of flowering resources is increasing in land use systems (see also Thiollay 1995). Similar pattern was found when using the call-based method (Waltert *et al.* 2005b). Food resource is not the only parameter influencing the highest species richness and abundance of this group in land use systems. The feeding height parameter should also be considered, as the canopy nectarivorous birds could

not be trapped with our mist-net sampling method in natural habitats (read also Driscoll & Kikkawa 1989). Our results showed that species usually found at canopy level were more easily trapped in annual cultures. These results may imply that this group is less sensitive to habitat modifications.

V.4.7. General feeding groups comparison

In general, insectivores, omnivores and nectarivores were respectively the first, second and third most abundant groups of our mist-netted community. Similarly in Bossematié Forest Eastern Côte d'Ivoire, "Nectarivores" and mixed feeders both were significantly more abundant than specialised fruit feeding species or granivores (Waltert 2000a). While, captures of insectivores were significantly higher in natural habitats than in land use habitat types in our study case, granivores, omnivores and to some extent frugivores showed the opposite. These findings supported the tentative conclusion that, in heavily logged forest, species with a more opportunistic feeding behaviour are more abundant than specialised feeders (Waltert 2000a), although in contrast to results from primary forest where, except from carnivorous species, marked differences in density between main dietary guilds did not occur (Thiollay 1994).

V.4.8. Biome-restricted species

Surprisingly, the mist-net data revealed that biome-restricted species richness and diversity are lower in natural habitats as compared to land use systems. Contrary, with the call-based method, a clear decrease in species richness from forest to farmland was found (Waltert *et al.* 2005b). This means that a high proportion of this group of species tolerate well less optimal conditions particularly if the primary forest is not far, and seems to be favoured by a dense understorey vegetation. In other words, many true forest species could successfully use land systems at least for food in periods of stress particularly when their territories are situated in the nearby natural habitats. Similarly, Haffer (1974) and Cracraft (1985) hypothesised that species with restricted ranges could possibly be better adapted to local conditions, and thus be competitively superior to "alien" species and be more abundant. But, abundance pattern showed the opposite and understorey bird species with a smaller geographic range showed a preference for near-primary forest where as those with a larger geographic range prefer more disturbed habitats. Similar result was found in Bossematié Forest where species with

restricted geographic ranges had an overall higher proportion of captures in the control compartment than in the disturbed compartment (Waltert 2000a). Other studies have found similar patterns (e.g. Kattan 1992, Hamer *et al.* 1997).

V.4.9. Forest canopy birds in land use systems

Although it was not possible to compute rarefied species richness of upper-strata birds, it is evident, from data presented in Table 2, that modified habitats are significantly richer than near-primary forest for both mid- and upper strata groups and a significant, positive relationship was found between average foraging height and relative preference for annual cropland. This had contributed at least partly to the patterns found for overall understorey bird species richness and abundance (see above). Similar results were also found in the Bossematié Forest (Waltert 2000a) where some midstorey and canopy dwellers were more often captured in the disturbed compartment, as compared to true understorey species, leading to the conclusion that the community comparisons between compartments had been considerably influenced by shifts in vertical distributions of species (see also Levey 1988, Driscoll & Kikkawa 1989). It was also the case in Central Sulawesi where understorey bird data could have been strongly influenced by an increased proportion of higher-strata species (Waltert *et al.* 2005a). Similar patterns were also found for butterflies (Wood & Gillman 1998; Fermon *et al.* 2005). But, a contrasting situation apparently appeared in Ghanaian forests where densities of canopy species were relatively unaffected by logging and might be largely due to the relatively moderate logging levels (*c.* 1 tree/ha) (Holbech 1996).

V.4.10. Size class foliage gleaners and habitat modifications

The call-based method showed a steady decrease of species richness of large and medium-sized foliage gleaners with increasing habitat modifications, as a result of the reduction in the vegetation structure complexity in modified habitats that could reduce variability in foraging substrates (Waltert *et al.* 2000b). In contrary, mist-net data for the concerned groups revealed lowest species richness and diversity in near-primary forest. This result seemed to be influenced more by the shift in vertical stratification of forest birds in land use systems than the size of understorey birds as a modest, significantly positive correlation was found between body mass and preference for near-primary forest. Similarly, larger species (indicated by

weight) showed a higher preference for the control compartment than smaller ones in the Bossematié Forest (Waltert 2000a).

V.4.11. Comparing species-level responses of the two methods

Out of the 93 species captured, 12 were found using the four habitat types as compared to the 91.7% of the 180 species found with the call-based method (Waltert *et al.* 2005b). This means a great variation in understorey bird species composition between habitat types. We also found low similarities in understorey bird species composition between natural forests and land use types. This indicated a much higher understorey bird species turnover as compared to that of the call-based method. Also just 5.4% of the captured species showed significant responses to habitat types after sequential Bonferroni corrections indicating, if not influenced by sample size, a much lower habitat specificity in understorey birds as compared to the 14.4% of species obtained with the call-based method (Waltert *et al.* 2005b).

V.5. Conclusion

Patterns of bird data from mist-netting were different from that of the call-based method on the same plots (Waltert *et al.* 2005b); thus, interpreting presence/absence data should be done with caution (Hughes *et al.* 2002) particularly at small scales. Understorey birds were surprisingly more diverse and abundant in disturbed habitats in our case study, except for the group of ant-following birds, and to some extent overall insectivores, that seemed to be more vulnerable to disturbance. This could be explained by the maintenance of some fallow lands and trees in the agricultural matrix and the closeness of the pristine forest. It was evident when interpreting the abundance distribution of different habitat types. Species with smaller geographic range and larger body mass preferred the near-primary forest habitat. Species usually found at canopy level shifted to understorey in annual croplands. Interpreting data on the number of captures only could lead to the conclusion that our studied plots have almost the same habitat quality, and even near-primary forest having the lowest quality. But, we should also consider that in territorial species under high population pressure, and in a complex habitat mosaic, an inverse relationship between relative abundance and habitat quality may exist due to higher movement rates of sub-ordinate individuals resulting in a much higher capture rate in sub-optimal habitats than in optimal habitats (see Schemske & Brokaw 1981, Levey 1988, Lambert 1992, Winker *et al.* 1995). We nevertheless might

conclude that degraded habitats temporally serve as feeding places for many forest birds, outside their normal territories, particularly at period of food scarcity. So, let us then analyse other habitat factors relevant for birds in the following chapters.

INDICATORS OF HABITAT QUALITY AND
DIRECT FACTORS INFLUENCING
UNDERSTOREY BIRD COMMUNITY PATTERNS
ALONG A GRADIENT OF FOREST CONVERSION

- VI. Ground and shrub nest predation risk, and availability of cavity nesting sites
- VII. Bird food resources: Leaf-litter invertebrates, abundance and species richness of fruiting and flowering trees, and leaf litter area and weight
- VIII. Body weight, parasite loads, fault bars, fluctuating asymmetry and adult territory owners

VI

GROUND AND SHRUB NEST PREDATION RISK, AND AVAILABILITY OF CAVITY NESTING SITES ALONG A GRADIENT OF FOREST CONVERSION

Abstract

Nothing is known on the reproductive success of tropical forest birds in the Central African region. We studied bird nests predation using a total of 240 artificial ground and shrub nests baited with ‘country chicken’ eggs for eight days in two natural and two land use habitat types in the Korup region, Cameroon. We also counted nesting cavities around the study sites’ center of 50 m radius. Our experiment indicated a low predation rate of 20%, of which 70.83% and 20.17% were respectively from ground and shrub nests. Habitat types did not show any effect neither on overall artificial nest predation, nor on that of ground or on shrub nests. Predation rates differed significantly between ground and shrub nests, with largest difference in agroforestry systems. The daily predation rate did not differ significantly between habitat types, neither for ground nor for shrub nests. Rats, squirrels and snakes were identified as the most common egg predators, followed by humans, with respectively *ca.* 59.5% and 16.2% of the 74 identified predator indices. Neither overall predator indices, nor from ground or from shrub nests were significantly different between habitat types. Predator indices from ground nests (70.3%) were significantly different from that of shrub nests (29.7%). For each of the seven predator groups concerned with ground nests, no significant difference was found between habitat types. But two of the four predator groups concerned with shrub nests showed significant differences between habitat types. No significant correlation was found between vegetation parameters and nest predation intensities. Bird nesting cavities showed a clear increasing pattern with increasing habitat modifications, but no clear defined patterns were observed with the number of bird nesting trees and the number of bird nesting tree species although they showed the highest values in annual cultures. Owls (Tytonidae), Hornbills (Bucerotidae) and Trogons (Trogonidae) were found using trees mostly from natural habitats, but almost all tree species in all habitats were used the same way by birds to dig their nesting cavities. To compare with other studied from tropical regions, our

area experienced the lowest predation rate, meaning a higher reproductive success, and totally different predation patterns. Land use systems seemed to be more favourable for cavity nesters, but Owls, Hornbills and Trogons preferred the calm of natural forests.

Key words: Bird viability, Cameroon, Cavity nesters, Land use, Nesting sites, Nests predation, Tropical rainforest.

VI.1. Introduction

As tropical rainforests are being converted into agricultural lands, the conservation of biodiversity will depend not only on the maintenance of protected areas, but also on the scope for conserving within the agricultural matrix in which they are embedded (Harvey *et al.* 2006). The Cameroonian rainforest is increasingly converted by shifting cultivation as well as the creation of industrial tree plantations and timber operations (Zapfack *et al.* 2002). Yet, very few are known on the effects of these conversions on tropical bird populations, particularly as far as nest loss and nesting sites are concerned. Tropical birds are often reported to suffer higher rates of nest loss (Ricklefs 1969, Skutch 1985, Martin 1996, Pangau-Adam *et al.* 2006). Higher levels of nest loss generally stimulate a large number of nesting attempts each breeding season, resulting in reducing clutch size and increasing adult survival (Cody 1966, Ricklefs 1977), but with variations according to species, nest type, nesting sites and years (Sieving 1992, Robinson *et al.* 2000). Many studies in the Neotropics indicated higher predation rate in forest edges than forest interiors (e.g. Loiselle & Hoppes 1983, Gibbs 1991, Cooper & Francis 1998, Sodhi *et al.* 2003) as a results of more diverse predator assemblages in forest margin. In Sulawesi, while shrub nests experienced significantly higher predation rates in forest margin areas than in natural forest, ground nests did not differ significantly between habitat types (Pangau-Adam *et al.* 2006). It is also known that ground-nesting birds are often the first to disappear after fragmentation of tropical forests (Thiollay 1992, Stouffer & Bierregaard 1995) and that understorey birds are the most sensitive group to forest disturbances (Waltert 2000b, Waltert *et al.* 2005b). Little is known on the reproductive success of tropical forest birds either in disturbed or undisturbed habitats (Pangau-Adam *et al.* 2006). For the long-term viability of birds in the agricultural landscape matrix, one of the essential factors is the sufficiently low level of predation as nest predation could seriously

reduce eggs and nestling survival known to be primary determinants of reproductive success in bird communities (Loiselle & Hoppes 1983, Laurance *et al.* 1993).

Since tangible nest predation events are hard to observe, one indirect way to determine how well bird species may be reproducing in their habitats is through artificial nest experiments (Wong *et al.* 1998), which have been used frequently in several studies for testing various ecological and behavioural hypotheses of predation theory (Major & Kendal 1996). Even though those nests are neither defended by adult birds nor as well concealed as most natural nests, it is considered that the predator fauna detect and respond to artificial nests in a manner similar to natural nests (Martin 1987, Gibbs 1991, Carlson & Hartman 2001). To get an index of predation rates (Andr  n 1995, Pangau-Adam *et al.* 2006), we used artificial ground and shrub nests in two natural habitats and two land use types. We also counted nest cavities around the plots center to check bird nesting sites conditions. Our aim is to detect patterns change of key parameters for bird population development. We hypothesised that (1) nests predation will also be high in our study area as in other tropical forest regions (see e.g. Ricklefs 1969, Skutch 1985, Martin 1996, Pangau-Adam *et al.* 2006), (2) the level of predation will increase with increasing modifications, (3) ground nests will be more sensitive to predation than shrub nests, (4) different predators will respond in different ways to habitat modification, (5) nesting cavities, nesting trees and nesting tree species will decrease with increasing disturbance. To our knowledge, the present study constitutes a first trial of such kind at least in the Central African region, and is lead to provide comparable results to that of other tropical forest regions.

VI.2. Methods

VI.2.1. Data collection

Data were collected from beginning January to beginning April 2006 i.e. between mid dry season and beginning rainy season (see also Sieving 1992). But, it should be noted that since one year before our field research, there was no real dry season as rains were common the year round.

At each of the 24 study sites distributed equally over the four habitat types (§ IV.), a line transect of 120 m crossing the centre of the plot was established. On each transect, five experimental subplots consecutively situated at *ca.* 30 m intervals, were set up. A subplot consisted of one ground and one shrub nests set up at *ca.* 15 m from each other and marked with red tape tied nearby. To further facilitate relocation, ground nests were placed near

buttresses of trees or at the base of larger saplings; a practice carried out also by previous researchers (e.g. Wong *et al.* 1998, Pangau-Adam *et al.* 2006) to simulate the nest sites of ground-nesting forest birds such as quails, rails, doves and pittas (Coates *et al.* 1997). Shrub nests were installed between 1 and 2 m above the ground in shrubs or in forked branches of trees imitating the nest type of understorey flycatching species such as monarchids (e.g. *Terpsiphone rufiventer*). As nest appearance and site of placement could strongly influence predator perceptions, the percentage of shrub cover for each shrub nest was estimated (Sieving 1992). Shrub cover of each nest should indicate the degree to which nests would be concealed from the side or from above. We also measured the height of shrubs carrying the nest. Nests were made of wire baskets, 12 ± 2 cm diameter by 4 cm depth and 10 ± 2 cm diameter by 5 cm depth respectively for ground and shrub nests, lined on the inside and outside with dry vegetation (leaves and grasses) so that no part of the nest could be seen through the grass cladding. A total of 240 (120 ground and 120 shrub) nests were installed. Small size village chicken eggs also called ‘country eggs’ (35-40 x 25-30 mm) were used in replacement of quail (*Coturnix japonicus*) eggs experimented by other authors (e.g. Pangau-Adam *et al.* 2006) and which could not be found in the area. Two of these were put in each nest. Nests and eggs were placed outside for one week before usage to reduce any artificial odour. Nests were installed at the same time for the six transects/plots of a same habitat type, before shifting to another habitat. During the setting up and controls, all nests and eggs were handled using gloves and boots to minimize human scent (Laurance *et al.* 1993). After installing nests and eggs on suitable places, leaves were kindly removed from the litter so as to detect any animal prints around the nests. Eggs were also replaced if spoiled. Nests were controlled after eight days, and counted as preyed upon if one or both eggs are missing, eaten, cracked or damaged. During the control, animal footprints were studied carefully around the predated nests with the help of a local hunter. Eggshells were also checked 5 m around the nests and studied well to identify the concerned groups of predators.

A search around the study site centers of 50 m radius was made for trees with nesting cavities. Each of such trees was identified to species. The distance from the base of each of these trees to the plot central point was measured in order to estimate the density of nesting cavity trees. Notes were taken on the number of cavities in each tree, the bird species entering into these cavities at any time, whether during the count period or the subsequent search within the plot.

Vegetation data were collected in the same plots as for the artificial nests experiment, between December 27th, 2003 and March 10th, 2004, and were already published in Bobo *et al.* (2006a) and Waltert *et al.* (2005b).

VI.2.2. Data analysis

Predation intensities were estimated as the number of artificial nests preyed upon after eight days at each plot; predated eggs intensities were not evaluated, as two eggs in the same nest were probably not preyed independently (Pangau-Adam *et al.* 2006). These intensities were expressed as the percentage of nests preyed in each plot and one-way ANOVA was used to detect significant differences between habitat types. Predation rates on artificial ground and shrub nests were compared using a t-test. Non-parametric analysis of variance (Kruskal – Wallis ANOVA) was used to determine if the frequency of predator groups differed among habitats.

For each habitat type studied, densities of nesting cavity trees, based on a single detection function for cavities at all plots combined, were estimated using the Half-normal Cosine model provided by the DISTANCE 4.0 programme (Buckland *et al.* 2001). For each study site, we also counted the total number of bird nesting cavities, bird nesting trees and bird nesting tree species. These parameters were used in a one-way ANOVA in order to analyse the effects of habitat types. Means are given with standard deviation if not mentioned otherwise. Tukey's Honest Significance Difference-Test (HSD test) was used for multiple comparisons of means.

Spearman rank correlation coefficients r_s were also established to describe relationships between predation intensity of artificial overall, ground and shrub nests, shrub nests percentage cover and height and tree density (with and without cocoa/coffee trees), basal area (with and without cocoa/coffee trees), understorey plant density.

Spearman correlations, one-way ANOVA, and all other statistical analyses were performed using STATISTICA 6.0 (StatSoft 2001).

VI.3. Results

VI.3.1. Nest predation

VI.3.1.1. Predation intensities and effects of habitat and nest types

A total of 48 (20%) out of 240 nests installed were preyed after 8 days of experiment in each habitat. Out of the 48 nests preyed, 34 (70.83%) and 14 (20.17%) were respectively from ground and shrub nests.

Overall predation rate was not significantly different between habitat types (One-way ANOVA, $F_{3,20} = 0.52$, $P = 0.67$). Habitat types did not show any effect neither on artificial

ground nests, nor on shrub nets (one-way ANOVA, ground nests: $F_{3,20} = 0.24$, $P = 0.87$; shrub nests: $F_{3,20} = 0.97$, $P = 0.43$, see Fig. 2). Predation rates (mean \pm SD) differed significantly between ground (14.17 ± 10.18) and shrub (5.83 ± 7.17) nests ($t = 3.12$, $df = 23$, $P = 0.005$). When comparisons are made between ground and shrub nests in each habitat, significant difference appeared just in agroforestry systems ($t = 2.71$, $df = 5$, $P = 0.042$) (see Table VI.1.). Daily predation rate did not differ significantly between habitat types, neither for ground ($F_{3,20} = 0.24$, $P = 0.87$), nor for shrub ($F_{3,20} = 0.97$, $P = 0.43$) nests (see Fig. VI.1.).

Table VI.1.: Differences in predation between artificial ground and shrub nests in the four habitat types.

Habitat	n	Nests preyed		df	t-test	P
		Ground	Shrub			
NF	30	8	6	5	0.67	0.53
SF	30	9	3	5	1.58	0.17
CF	30	7	2	5	2.71	0.042
AC	30	10	3	5	1.66	0.16

Notes: n = Total number of nests in each habitat type; Habitats are defined as NF for near-primary forest, SF for secondary forest, CF for agroforestry systems and AC for annual cultures.

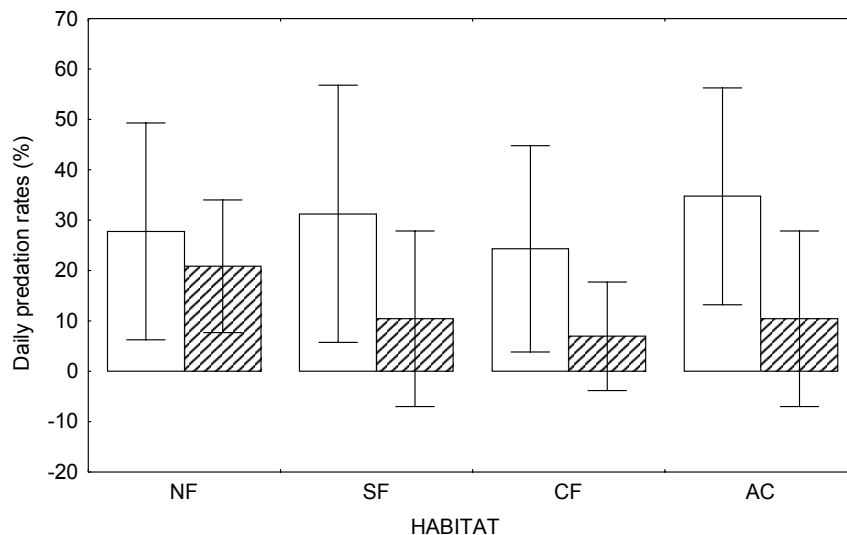


Figure VI.1.: Mean daily predation rates of artificial ground (opened bars) and shrub (shaded bars) nests; Error bars indicate standard deviation; See Table VI.1. for abbreviations of habitat types.

VI.3.1.2. Identification of predators' groups/other damaged nests reasons

In total 74 indices of predators have been identified, of which 70.3% are from ground nests and 29.7% from shrub nests (see Table VI.2.). The amount of indices from ground nests was significantly different from that of shrub nests ($t = 3.19$, $df = 23$, $P = 0.004$). Neither overall predator indices, nor from ground or from shrub nests were significantly different between habitat types (Kruskal –Wallis, Overall: $H_{3,24} = 1.43$, $P = 0.70$; from ground nests: $H_{3,24} = 1.11$, $P = 0.77$; from shrub nests: $H_{3,24} = 3.97$, $P = 0.26$).

From ground nests, seven groups of predators were identified as (group 1) rat, squirrel (32.7%), (group 2) snakes (26.9%), (group 3) human (17.3%), (group 4) monitor lizard (9.6%), (group 5) mongooses, palm civet, genets (7.7%), (group 6) dog (3.8%) and (group 7) Windfall (1.9%). For each of these seven groups, no significant difference was found between habitat types (Kruskal –Wallis, $P > 0.05$). But rat and squirrel had the highest indices in annual cultures and secondary forest; highest snake indices was found in natural habitats (NF, SF); secondary forest has experienced highest predator indices of groups 4 and 5; highest human and dog indices was found in land use systems (CF, AC), with no indices in natural habitats (see Table VI.2.).

Table VI.2.: Distribution of detected predators' indices between habitat and nest types.

Nest type	Predator groups	Habitat				<i>n</i>	% (<i>n</i>)	% (N)
		NF	SF	CF	AC			
Ground nest	Rat, squirrel (1)	2	4	2	9	17	32.69	22.97
	Snake (2)	6	4	2	2	14	26.92	18.92
	Human (3)	0	0	7	2	9	17.31	12.16
	Monitor lizard (4)	1	3	1	0	5	9.62	6.76
	Mongooses, Palm civet, Genets (5)	1	3	0	0	4	7.69	5.41
	Dog (6)	0	0	0	2	2	3.85	2.70
	Windfall (7)	0	1	0	0	1	1.92	1.35
	<i>n</i>	10	15	12	15	52	100.00	70.27
	%	19.23	28.85	23.08	28.85	100.00		
Shrub nest	Squirrel, Tree snake (1)	9	3	1	0	13	59.09	17.57
	Human (2)	0	0	2	1	3	13.64	4.05
	Lizard (3)	0	0	0	2	2	9.09	2.70
	Windfall (4)	0	0	0	4	4	18.18	5.41
	<i>n</i>	9	3	3	7	22	100.00	29.73
	%	40.91	13.64	13.64	31.82	100.00		
Overall	N	19	18	15	22	74		100.00
	%	25.68	24.32	20.27	29.73	100.00		

Notes: (): group numbers of predators; See Table VI.1. for abbreviations of habitat types.

From shrub nests, four groups of predators were identified as (group 1) Squirrel, snake (59.1%), (group 2) Windfall (18.18), (group 3) human (13.64%), (group 4) lizard (9.1%). Indices of the first group showed significant differences between habitat types: near-primary forest had a significantly higher indices as compared to annual cultures (Kruskal –Wallis, $H_{3,24} = 9.82$, $P = 0.017$). Shrub nests damaged by windfall were also significantly different between habitats; annual cultures having a significantly higher damaged indices as compared to other habitats (Kruskal –Wallis, $H_{3,24} = 9.82$, $P = 0.02$). Groups 3 and 4 indices did not showed significant differences between habitat types (Kruskal –Wallis, group 3: $H_{3,24} = 2.09$, $P = 0.55$; group 4: $H_{3,24} = 6.27$, $P = 0.099$): lizard was seen pushing shrub nest eggs on the ground in annual cultures and, more human signs were observed in agroforestry systems (see Table VI.2.).

All together, rat, squirrel and snakes have been identified as the most common eggs' predators in our study area, followed by human, with respectively 59.5% and 16.2% of all identified indices (see Table VI.2.).

VI.3.1.3. Correlation with vegetation parameters

There were only weak and non-significant correlations between any of the vegetation parameters and any of the artificial nest predation rates, neither from ground or shrub nest types, nor from both types together (in all the 35 cases, $r_s = [-0.22, 0.27]$, $P > 0.05$), although the percentage cover of shrubs had shown significant difference between habitat types (one-way ANOVA, $F_{3,20} = 14.68$, $P < 0.001$): shrub cover was highest in near-primary forest (mean \pm SD, 75.12 ± 2.04); it was significantly lower in agroforestry systems (44 ± 19.25 , $P = 0.001$) in secondary forest (39.12 ± 5.04 , $P < 0.001$) and in annual cultures (33.5 ± 12.96 , $P < 0.001$). Shrub nest height were not significantly different between habitat types (one-way ANOVA, $F_{3,20} = 0.62$, $P = 0.61$).

VI.3.2. Cavity nesting sites

VI.3.2.1. Density of bird nesting cavities

The table VI.3. is a compilation of distance analysis results of different habitat types.

Table VI.3.: Point estimates of bird nesting cavities.

Habitat	EDR (m)	DP	D (ha)
Overall	15.35±2.51	0.86	28.69±10.15
NF*	17.29±2.01	0.71	20.31±5.62
SF	46.17±10.11	0.60	3.49±1.97
CF*	16.09±5.79	0.89	20.88±15.91
AC	38.67±6.92	0.66	5.42±2.39

Notes: Point estimates are given \pm Standard Error; EDR: Effective detection radius; DP: Detection probability; D: Density; *: Small number of observations, which do not give reasonable results. See Table VI.1. for abbreviations of habitat types.

From Table VI.3., it is clear that the smaller number of observations of bird nesting cavities, particularly in NF and CF sites, cannot give reasonable estimates of the densities with the Distance programme.

VI.3.2.2. Abundance of nesting cavities and trees, and nesting tree species for birds

In the 24 study sites, a total of 105, 34 and 14 bird nesting cavity, bird nesting tree and bird nesting tree species records respectively (single detections of individual nesting cavities, nesting trees and nesting tree species) were obtained. Neither the number of bird nesting cavities, nor the number of bird nesting trees and the number of bird nesting tree species were significantly affected by habitat type (One-way ANOVA, for the number of bird nesting cavities $F_{3,20} = 1.53$, $P = 0.24$; for the number of bird nesting trees $F_{3,20} = 0.70$, $P = 0.56$; for the number of bird nesting tree species $F_{3,20} = 0.76$, $P = 0.53$).

But bird nesting cavities showed a clear increasing pattern with increasing habitat modifications: Highest number of bird nesting cavities was found in AC (mean \pm SD; 12.75 ± 4.19); it slowly decreases to $8.67 (\pm 9.81)$ in CF, to $5.25 (\pm 6.13)$ in SF and to $2.33 (\pm 0.58)$ in NF (see Fig. VI.2A.).

No clear defined pattern was observed with the number of bird nesting trees, but highest record was found in AC (3.25 ± 0.96); it was slightly lower respectively in SF (2.25 ± 1.89), CF (2.00 ± 1.73) and NF (2.00 ± 0.00) (see Fig. VI.2B., Table VI.4.).

No clear defined pattern was also observed with the number of bird nesting tree species, but highest species richness was found in AC (2.50 ± 1.00); it was slightly lower respectively in NF (2.00 ± 0.00), SF (1.75 ± 0.96) and CF (1.33 ± 0.58) (see Fig. VI.2C., Table VI.4.).

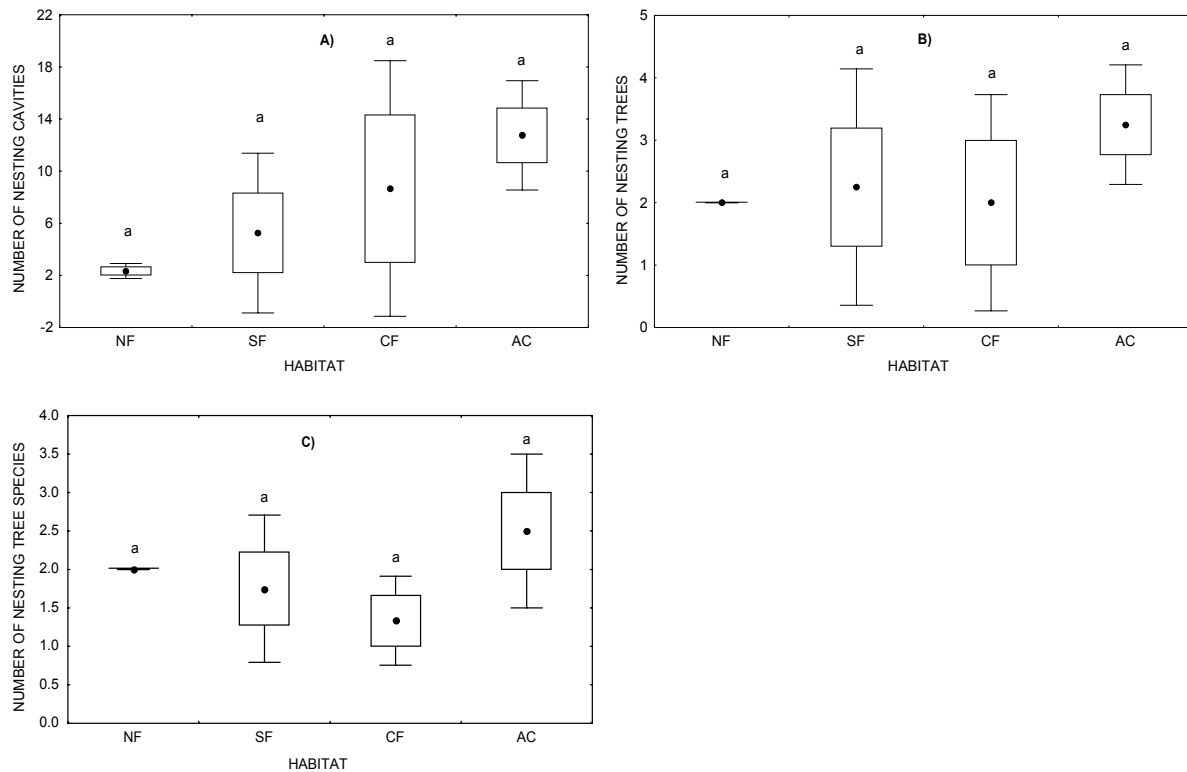


Figure VI.2.: A): Number of bird nesting cavities, B) number bird nesting trees and C) number of bird nesting tree species; The points indicate the mean values; Error bars indicate mean \pm standard deviation and the boxes indicate mean \pm standard error; a in all cases indicates no significant differences (Tukey 's Honest Significant Difference-Test). See Table VI.1. for abbreviations of habitat types.

Together, ten bird families were found using tree cavities in the four habitat types. But, the Owl (Tytonidae), Hornbill (Bucerotidae) and Trogon (Trogonidae) families were using trees mostly from natural habitats (see Table VI.4.). Nevertheless, almost all tree species in all habitats were used the same way by birds to dig their nest cavities.

Table VI.4.: Bird nesting tree species and abundance in different habitat types. The dry or fresh aspect of the tree where birds used to dig the cavities is mentioned. Also, the corresponding bird families using the nesting cavities are presented.

Tree species	Habitat				Aspect	Bird family
	NF	SF	CF	AC		
<i>Albizia zygia</i>	1	1	0	0	Dry	Tytonidae
<i>Calpocalyx sp.</i>	1	0	0	0	Dry	Capitonidae
<i>Erithrophleum sp.</i>	0	0	3	0	Dry	Capitonidae
<i>Fagara macrophylla</i>	1	0	0	0	Fresh	Cuculidae, Trogonidae
<i>Ficus sp.</i>	0	2	0	0	Dry	Capitonidae, Alcedinidae
<i>Hyiodendron sp.</i>	0	0	1	0	Fresh	Trogonidae
<i>Morinda lucida</i>	0	2	0	0	Dry	Capitonidae, Tytonidae
<i>Musanga cecropioides</i>	0	0	1	0	Fresh/Dry	Capitonidae, Tytonidae
<i>Picnanthus angolensis</i>	1	0	0	0	Fresh	Tytonidae
<i>Spathodea campanulata</i>	0	0	1	0	Fresh	Alcedinidae
<i>Terminalia ivorensis</i>	1	0	0	2	Fresh	Cuculidae, Tytonidae
<i>Terminalia superba</i>	0	1	0	7	Dry	Capitonidae, Picidae, Dicruridae, Sturnidae, Bucerotidae
<i>oubanguia alata</i>	1	0	0	0	Fresh	Bucerotidae
<i>Xylopia aethiopica</i>	0	3	0	4	Dry	Capitonidae
Total	6	9	6	13		

VI.4. Discussions

Our experiment indicated an overall low nest predation rate of 20% as compared to the 61.7% obtained in Palolo valley and 62.3% in Napu valley, Sulawesi (Pangau-Adam *et al.* 2006). In our case study, overall daily predation rates are low and range from 4.86% in near-primary forest, 4.17% in secondary forest and 3.13% in agroforestry systems to 4.51% in annual cultures. This low level of predation could probably be explained by what we can call ‘a general wildlife crisis’ observed in the study area. Big and medium sized mammals are already almost all hunted out. Few small mammals persist in primary forest, but seem to be seriously affected by fence traps and chemical products used in the nearby cocoa/coffee farms.

As in our study, many other studies indicated that ground nests have experienced significantly higher predation rates as compared to shrub nests, as a result of a high number of rodent species and their abundance (e.g. Loiselle & Hoppes 1983, Wilcove 1985, Martin 1987,

Pangau-Adam *et al.* 2006). Snakes may have also contributed a lot in our study area. In fact, predator assemblages from ground nests were different from that of shrub nests although some species may prey in both nest types. The first was constituted of rat and squirrels, mongoose, palm civet and genet, monitor lizard, snake, human and dog while the second was made of squirrel, tree snake, human and lizard. Avian species can be added to this last group (see also Andrén *et al.* 1985, Cooper & Francis 1998) as these predators are found in the study area (see Rodewald *et al.* 1994) but indices were not easy to detect on shrub nests. Human also play a big negative role in the breeding success of understorey birds in land use systems by collecting bigger eggs (e.g. of *Francolinus spp.*) and by destroying nests when clearing farms and fallow lands. Many studies in tropical forest have identified small mammals as being the main predators on ground nests (Gibbs 1991, Laurance *et al.* 1993, Wong *et al.* 1998, Estrada *et al.* 2002). In Sulawesi, small mammals appeared to be the major predators on both ground and shrub nests (Pangau-Adam *et al.* 2006). This is also the case in our study area where, if including predation by reptiles, both encountered for 74.32% of all.

As the Sulawesi study, our findings on ground nests do not also support the edge effect hypothesis. In fact, our ground nest predation rates were not significantly difference between habitat types, ranging from 13.33% in near-primary forest, 15% in secondary forest, 11.67% in agroforestry systems to 16.67% in annual cultures. Edge effects on ground nests predation were not also evident in many other studies (e.g. Arango-Vélez & Kattan 1997, Wong *et al.* 1998, Carlson & Hartman 2001). This was also the case in Costa Rica at edges between forest and pasture (Gibbs 1991). The lack of edge effects on predation rate in the forest-field transition might be related to the extremely different landscape surroundings of the forest habitat that do not support the activity of several potential nest predators (Gibbs 1991). Similarly, Pangau-Adam *et al.* (2006) suggested that the edge type might probably cause the absence of an edge effect in forest margin habitats in Central Sulawesi, which was the transition between two structurally different landscapes (forest – agricultural field edges). In our case study, this argument can be expressed as a high turn over rate of the remaining forest-dwelling predators (snakes, mongooses, palm civet and genets) that are easily replaced along the gradient of forest disturbance by predators associated with modified habitats (rats, squirrels, dog, human). In other terms, high intensity of human activities in land use systems, including fence traps around farms in our case, probably prevent forest-dwelling predators from entering these habitats (see also Carlson & Hartman 2001, Pangau-Adam *et al.* 2006). Other reason could be that chemicals used in the agroforestry systems might have already killed numerous of these predators in our study area. However, some studies from the

Neotropics and Southeast Asia indicated different patterns. In fact, edge effects were detected on ground nests predation at various edges, including transitions between a minor road and forest, between logged and unlogged forest as well as forest and pasture edges (Burkey 1993, Cooper & Francis 1998, Estrada *et al.* 2002). In Costa Rica, Gibbs (1991) also documented an increased predation risk on ground nests at edges between indigenous and second growth forest.

Similar to ground nest patterns, habitat types did not show any effect on artificial shrub nets in our study area, thus once more not supporting the edge effect hypothesis. The reasons are similar to that of ground nests. More, very weak non-significant correlations were found between shrub nest predation rates and shrub percentage cover and height, meaning that predator species did not take the advantages of less vegetation cover in land use systems to find nests easily as in Sulawesi (Pangau-Adam *et al.* 2006). Also arboreal predator species were rare in degraded habitats, and most nest attacks or damages were done by human and windfall. Thus, the travel lines normally used by potential predators to enriched land use systems in predator assemblages (e.g. Andrén 1995) are hampered in our study area by fence traps. This could have caused an increased of small nest predators abundance in disturbed habitats as top predators of natural forests (e.g. palm civet, monitor lizard, mongooses, genet) may be blocked (see also Terborg 1974, Crook & Soulé 1999), but we are suspecting the use of chemical products in the agricultural landscape to have killed many of them. This could probably also explain why we obtained a relatively higher non-significant predation rate in near-primary forest as compared to other habitats. Different results were found in both Napu and Palolo valleys in Central Sulawesi where forest margin areas showed significantly higher predation rates on shrub nests as compared to natural forests (Pangau-Adam *et al.* 2006).

Contrary to our prediction, neither the number of bird nesting cavities, nor the number of bird nesting trees and the bird nesting tree species were significantly affected by habitat type. But, the number of bird nesting cavities showed a clear increasing pattern with increasing habitat modifications. Although the tree numbers and species used by birds to dig their nesting cavities are almost the same between habitat types, annual croplands showed highest richness and density, probably because of more dead woods. Owls (Tytonidae), Hornbills (Bucerotidae) and Trogons (Trogonidae) were found using trees mostly from natural habitats, but almost all tree species in all habitats were used the same way by birds to dig their nest cavities.

VI.5. Conclusion

As it is considered that the predator fauna detect and respond to artificial nests in a manner similar to natural nests (Martin 1987, Gibbs 1991, Carlson & Hartman 2001), the first types can be used to predict real predation patterns although the selection of nesting sites plays a great role in the nest predation probability (Collias & Collias 1984). Therefore, we can conclude that (1) nest loss is much lower in our study area as compared to other tropical forest regions meaning that our avian breeding success could be better, but at least for some species the clutch size and number of nesting attempts in each breeding season still need to be investigated before any definitive confirmation, (2) there is no sensitive effect of habitat types on nests predation, (3) ground nests are more vulnerable to predation than shrub nests, particularly in modified habitats, (3) small mammals and reptiles are the most common predators. If dead trees are left in the agricultural matrix, land use systems can be of much higher value for birds than natural habitats as far as nesting sites for most cavity nesters are concerned. But it is clear that some species like Owls, Hornbills and Trogons prefer to dig their nesting cavities in natural habitats.

VI.6. Limitations to artificial nest predation experiment

The eggshells of ‘country fowl’ eggs that we used may be harder than natural bird eggs, thus limiting predation by some small mammals (see also Major & Kendall 1996). ‘Country fowl’ eggs might have introduced a bias in the abundance of predators found as they favorably attract predators like snakes that usually search for eggs right in houses and poultries. The season might have also influenced the results as our investigations started before the beginning of the main breeding season when maybe predators were not yet very active; but for e.g. in Central Panama, peak nest losses occurred immediately before the onset of breeding in understorey insectivorous birds (Sieving 1992). Also, years of study could change the patterns as in Panama with natural nests (Robinson *et al.* 2000). We also lacked the automatic camera to film predation events.

VII

BIRD FOOD RESOURCES: LEAF-LITTER INVERTEBRATES, ABUNDANCE AND SPECIES RICHNESS OF FRUITING AND FLOWERING TREES, AND LEAF-LITTER AREA AND WEIGHT ALONG A GRADIENT OF FOREST CONVERSION

Abstract

This chapter aimed at assessing food availability for selected forest birds (terrestrial insectivores and frugivores/nectarivores) as a mean to persist in modified habitats. Leaf-litter invertebrates, fruiting and flowering trees, as well as leaves of the litter were surveyed in 24 sampling stations distributed equally over our four habitat types. Arthropods were captured using repeated sweep net samples from the herb layer and selected understorey trees, sorted to order and measured to the nearest millimeter. Invertebrates of the leaf-litter were sampled by shoveling the litter and a few millimeters of the topsoil using a dustpan onto a sieve of 6 mm mesh width. A search for trees in fruit or flower was made and the distance from the base of each recorded tree to the plot center was measured. Ten common leaves of the litter were randomly selected and weighted, and their area was later estimated. Invertebrate order richness, abundance and average length increased significantly from natural to modified habitats. Although similarity between sites was high, all above 80%, the four land use types differed in invertebrate order composition, the difference being smaller among annual crop sites. Fourteen of the 28 invertebrate orders recorded showed significant responses to habitat types. Although no clearly defined patterns were observed in flowering and fruiting tree species richness and density, near-primary forest showed values significantly lower compared to other habitat types. Two flowering and five fruiting tree species known to invade degraded habitats were found to be the most attractive for many bird families. Overall invertebrate abundance was strongly negatively correlated with ant-following bird species richness and abundance. All significant correlations found between the fruiting and flowering trees, and abundance or species richness of the studied bird groups/guilds were moderate and positive, indicating that there are many understorey birds that use trees for feeding on fruits and

flowers, most of which were found in land use habitats during the sampling period. Overall mean leaf area and weight were significantly affected by habitat types; intermediate habitats showed highest leaf area than near-primary forest and annual cropland, and natural habitats showed highest leaf weight than land use systems. While ant-following bird species richness (and abundance) decreased from forest to farmland, there was no significant correlation between this parameter and ground invertebrate abundance. While the relationships between the leaf area and the respective ground foraging bird groups studied were all insignificant, the leaf weight and the respective ground foraging bird groups studied were all strongly, positively and significantly correlated. In conclusion, the reasons for the higher abundance of ant-following birds in natural habitats might not be directly related with the parameters studied. However, the higher abundance of flowering and fruiting trees in land use systems might largely explain, at least temporally, the occurrence of several understorey forest birds in modified habitats.

Key words: Biodiversity conservation, Cameroon, Invertebrate, flowering and fruiting trees, Land use systems, leaf-litter area and weight, Tropical rainforest, Understorey bird community.

VII.1. Introduction

The debate on how much biodiversity can be sustained in disturbed forests particularly in the Afro-tropical context is still ongoing. The conversion of tropical primary forests into various land use systems has serious impacts on the distribution, community structure and population characteristics of flora and fauna (e.g. van Gernerden 2004, Waltert *et al.* 2005b). Anthropogenic habitats are largely unknown in terms of their contribution to biodiversity conservation (Schulze *et al.* 2004b, Waltert *et al.* 2004). They may be important in terms of preserving at least a fraction of tropical biodiversity (Hughes *et al.* 2002, Waltert *et al.* 2005b) of which insects are a major part, but few data are available (Holloway *et al.* 1992, Eggleton *et al.* 1995, Lawton *et al.* 1998). Many authors suggest to redesign anthropogenic habitats so that their use is compatible with the use by a broad array of other species (Rosenzweig 2003, van Gernerden 2004) to avoid biodiversity loss.

Many studies confirmed the disappearance of forest understorey insectivorous birds from forested habitats generally as a result of their high habitat specificity, low mobility, and high

restriction to forest interior (e.g. Thiollay 1992, Kattan *et al.* 1994, Canaday 1996, Stratford & Stouffer 1999). Also, in an Amazonian forest bird community, the spot-diversity of an ecologically complex primary forest (on a few hectares) was very high due to the year-round availability of major resources (Terborgh *et al.* 1990). In fact, in contrary to our results from the call-based method (Bobo 2004, Waltert *et al.* 2005b), overall understorey bird species richness, when using the mist-net data, showed an increasing tendency with increasing habitat modifications (read also Waltert 2000a,b), although some understorey insectivorous bird groups showed decreasing patterns (read Chapter V.). From the four main hypotheses generally used to explain this decline (see Şekercioğlu *et al.* 2002), the food scarcity hypothesis (Ford *et al.* 1996, Burke & Nol 1998, Zanette *et al.* 2000) is of particular interest in our trials to understand some of our earlier findings (§ Chapter V.). One main food for birds in our study area namely fruit feeding butterflies, although significantly affected by habitat modification, showed significantly highest species richness and abundance in secondary and agroforestry sites as compared to near-primary forest and annual crop sites (Bobo *et al.* 2006b). Studies at Pasoh Forest Reserve (Negeri Sembilan, Peninsular Malaysia) indicated a less abundance of food resources, particularly flowers, fruits and arthropods, in the regenerating than in the virgin forest (Wong 1986).

This chapter aimed at assessing food availability for selected forest birds (terrestrial invertebrates and frugivores/nectarivores) as a mean to persist in modified habitats. Leaf-litter invertebrates as well as flowering and fruiting trees are known to be a key feeding substrates for birds, particularly terrestrial insectivores and frugivores (see also Şekercioğlu *et al.* 2002, Wong 1986). We also aimed at analysing the influence of leaves of the litter on some ground foraging bird species as it is believed that these species have problems in turning larger leaves of secondary forest trees like *Musanga cecropioides*. Leaf-litter invertebrates, flowering and fruiting trees were chosen because they show quick responses to ecosystem change and disturbance. Invertebrates also contribute to system sustainability through processes such as decomposition, energy transfer and pollination (Recher *et al.* 1993, Anderson & Sparling 1997). We hypothesised that: (1) Overall invertebrate order richness, abundance and average length, as well as flowering and fruiting tree species richness and abundance will be higher in natural habitats than in land use systems; (2) Different invertebrate orders will respond in different ways to habitat modifications; (3) Invertebrate orders composition, as well as flowering and fruiting tree species composition, will change along the habitat gradient; (4) Overall leaf-litter invertebrate order richness and abundance, as well as flowering and fruiting tree species richness and abundance, will be highly positively correlated to overall and to

terrestrial insectivorous, as well as to frugivorous bird group species richness and abundance; (5) The leaf-litter area and weight should increase with increasing disturbance but annual cultures should have the lowest values as tree leaves are rare and the litter is insignificant in this habitat type; (6) Also, a negative significant correlation should exist between both the leaf-litter area and weight, and the abundance of ground foraging birds or terrestrial insectivores such as larger thrushes, *Illadopsis spp.* and *Bleda spp.*.

VII.2. Methods

VII.2.1. Data collection

All data were collected during the dry season, although many rainy days were encountered each month. At each of the 24 sampling stations distributed equally over the four habitat types (§ IV.), eight haphazardly chosen 5 m x 5 m quadrates were established within a circular plot of 50 m radius to collect data on invertebrates from February 20th to March 21st, 2006. Within each quadrate, arthropods were captured using repeated sweep net samples from the herb layer and selected understorey trees, sorted to order, measured to the nearest millimeter and released. Invertebrates of the leaf litter were also sampled: the litter and a few millimeters of the topsoil were shoveled, 10 times per quadrate, with a dustpan onto a sieve with 6 mm mesh width, placed on a bucket containing a plastic bag (Zimmermann & Noske 2003). Invertebrates larger than the mesh were immediately sorted to order, measured to the nearest millimeter and released. Invertebrates passing through the mesh were collected, conserved in alcohol, examined later in the laboratory with a magnifying glass and sorted to order.

Also, within each quadrate, ten common leaves were selected randomly and weighted. Their length and width were measured using a tape meter. The contours of each of these chosen leaves were also drawn on newspapers with bold marker and labelled according to quadrates, plots and habitats, to be able to calculate reliable leaf areas later. For each species found, exact area of 30 leaves randomly chosen was calculated with the method of squares using millimetre papers. From the calculated area, a mean ratio to the convention area length x width per species was evaluated and was applied to all leaves of the corresponding species.

A search around the study site centers of 50 m radius was made for trees in fruit or flower between beginning January and beginning April 2006. Each fruiting and flowering tree was identified to species. The distance from the base of each of these trees to the plot central point was measured in order to estimate the density of fruiting and flowering trees. Notes were

taken when frugivorous-flower visiting bird species were observed feeding, at any time, whether during the counting period, the subsequent search within the plot, or during walks between census stations. For each feeding record, the bird species, the tree species, and whether birds fed on fruits or flowers were noted.

For understorey bird data, read Chapter V.

VII.2.2.Data analysis

Concerning invertebrates, sweep net data and data from leaf litter were mixed. For each study site, we counted the total number of orders detected after the repeated surveys, here referred to as “observed” order richness. Like for species (see Nichols & Conroy 1996), in most field studies, not all orders that are actually present are also recorded. Therefore, we also quantified an “estimated” order richness that takes into account that there are orders which are not actually recorded but which presence can be inferred from the pattern of observed order occurrence. To calculate estimated order richness, we used the first-order jackknife method that was initially designed to estimate population size from capture-recapture data, allowing capture probabilities to vary by individuals (Burnham & Overton 1978, 1979). As for estimations of species richness (see Heltshe & Forrester 1983, Colwell & Coddington 1994, Boulinier *et al.* 1998, Nichols *et al.* 1998, Chazdon *et al.* 1998, Hughes *et al.* 2002), this model can equally be applied to estimations of order richness. The Jackknife estimator is performing well if the proportion of rare species or orders (those which are represented in only one or two samples) is low (Chao 1987, Nichols & Conroy 1996). We also calculated beta-diversity between different sites using the classic Soerensen (qualitative) index (Magurran 1988). To calculate first-order jackknife estimates at each site and beta-diversity between different sites, we used the computer program EstimateSWin7.0.0 of Colwell (2000) by randomizing samples 100 times. Parameters were used in a one-way ANOVA in order to analyse effects of habitat type on order numbers. One-way ANOVA was also used to analyse effects of habitat type on order average length. Means are given with standard deviation if not mentioned otherwise. Tukey’s Honest Significance Difference-Test (HSD test) was used for multiple comparisons of means. We used the Morisita Horn index in a multidimensional scaling (StatSoft 2001) and ordinated our study sites two-dimensionally to depict invertebrate order similarity between habitat types.

For each habitat type studied, densities of fruiting and flowering tree species that frugivorous birds were seen feeding on were estimated using the Half-normal Cosine model provided by

the DISTANCE 4.0 programme (Buckland *et al.* 2001). The estimates represent the mean density of trees actually fruiting or flowering during the census period within the study sites. Detection functions were modeled for fruiting and flowering trees separately to obtain separate density estimates (Buckland *et al.* 2001, Marsden & Pilgrim 2003). For each study site, we counted the fruiting and flowering tree species and the respective total number of individuals detected during the sampling period. These parameters were used in a one-way ANOVA in order to analyse the effects of habitat type on tree species and individual numbers. Means are given with standard deviation if not mentioned otherwise. Tukey's Honest Significance Difference-Test (HSD test) was used for multiple comparisons of means.

For mist-netting data, after removing recaptured individuals from the analysis to avoid pseudo-replication, we counted the total number of understory bird species detected in each study site after 22 sampling hours, here referred to as "observed" species richness. A measure of the relative abundance was calculated as the total number of individuals detected at each site. These parameters were used in a one-way ANOVA in order to analyse effects of habitat type on understory bird species richness and abundance. Means are plotted with standard deviations. Tukey's Honest Significance Difference-Test (HSD test) was used for multiple comparisons of means. This was done for overall understory birds mist-netted as well as for overall insectivores and for different groups of insectivores, namely ant-followers, large, medium and small-sized foliage gleaners, known to be the most concerned groups that use invertebrates as main food resources. It was also done for frugivorous, nectarivorous, omnivorous and pycnonotids birds, known to be the most concerned groups/guilds that use fruiting and flowering trees as main food resources (read also Chapter V. for rarefaction analysis results).

Spearman rank correlation coefficients r_s were established to describe relationships between the overall understory bird species richness and abundance, as well as for different groups of understory insectivores studied, and overall invertebrate order richness and abundance, as well as for abundances of different invertebrate orders that are more than 250 individuals. Table-wide significances were calculated using the sequential Bonferroni correction (see Holm 1979, Rice 1989). Separately, the same types of relationships were also found between the studied frugivorous-flower bird groups species richness and abundance and their corresponding food resource parameters.

Average leaf-litter area and weight per species were calculated for each sampling station. Spearman-rank correlation coefficient was also computed in order to determine the

relationships between these parameters and ground foraging birds like large thrushes, *Illadopsis spp.* and *Bleda spp.*.

Spearman correlations, one-way ANOVA, and all other statistical analyses were performed using STATISTICA 6.0 (StatSoft 2001).

VII.3. Results

This section will deal mostly with results on invertebrates, flowering and fruiting trees, leaf-litter, and their correlation with the studied understorey bird groups. More detailed results on understorey birds (mist-netting data and rarefaction analysis) can be found in Chapter V. Observed species richness and abundance per plot for different understorey bird group studied are included in this section. Results on data collected with the call-based method can be found in Bobo (2004) and Waltert *et al.* (2005b).

VII.3.1. Leaf-litter invertebrates

VII.3.1.1. Invertebrate order richness, abundance and length at sampling stations

In the 192 quadrates, a total of 17,712 invertebrate records (single detections of invertebrate individuals) belonging to 28 identified orders were obtained. The number of invertebrate records per sampling station was significantly affected by habitat type (One-way ANOVA, $F_{3,20} = 39.82$, $P < 0.001$). Contrary to our prediction, invertebrate numbers showed a clear increasing pattern from NF to AC. Within the 50 m radius circular plot of each sampling station, the number of accumulated records after the eight quadrate surveys (replicates) was highest in AC (mean \pm S.D., 1244.2 ± 248.1), significantly lower in CF (828.2 ± 108.3 , Tukey's HSD test, $P < 0.001$), in SF (543.5 ± 101.9 , Tukey's HSD test, $P < 0.001$) and in NF (336.2 ± 97.4 , Tukey's HSD test, $P < 0.001$) (see Fig. VII.1A').

Jackknife order richness estimators revealed that assemblages of the studied invertebrate orders were not yet completely recorded: completeness of the inventories at single sites ranged from an average of 89% in the six SF and CF sites to 91% in the six NF and AC sites. Observed order richness was significantly correlated with estimates ($r_s > 0.95$, $P < 0.001$, $N = 24$, see also Fig. VII.1A.).

Also contrary to our predictions, invertebrate order richness showed an increasing pattern from natural to disturbed habitats: Highest order richness was found in CF with a mean

number of $23.3 (\pm 2.6)$ orders; it was slightly lower in AC (22.6 ± 1.1) and in SF sites (20.8 ± 3.8), and was significantly lower in NF sites (17.1 ± 2.4) (One-way ANOVA, for estimated species: $F_{3,20} = 6.65$, $P < 0.01$) (see Fig. VII.1A.).

Again in contrast to our hypothesis, average length of invertebrates showed a clearly increasing pattern with increasing habitat modification: Highest average length was found in AC (8.8 ± 1.4); it was slightly lower in CF (7.8 ± 1.5), and was significantly lower in SF (5.7 ± 0.6) and in NF sites (5.5 ± 1.3) (One-way ANOVA, $F_{3,20} = 9.93$, $P < 0.001$) (see Fig. VII.1A'').).

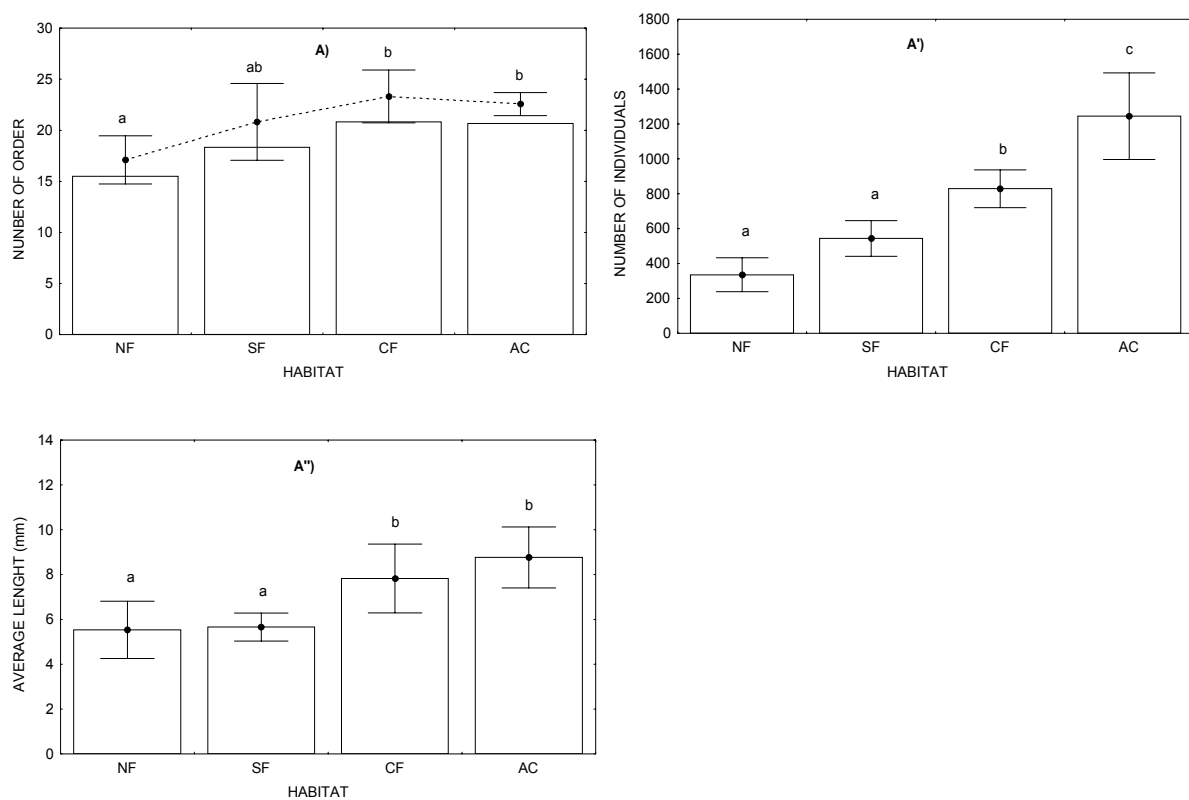


Figure VII.1.: Mean order richness (\pm standard deviation) based on the estimated number of invertebrate orders (dotted line) using the first-order jack-knife method (A); Additionally, the mean observed order richness (bars) is presented (A); Beside, overall mean abundance and average length in millimeter (\pm standard deviation) are also presented (A' and A''); Different letters indicate significant differences (Tukey's Honest Significant Difference-Test); Habitats types are NF for near-primary forest, SF for secondary forest, CF for agroforestry systems and AC for annual cultures.

VII.3.1.2. Invertebrate order similarity and composition

Pairwise similarity of invertebrate orders composition (mean Soerensen incidence index \pm S.D.) was highest among the six AC sites (0.92 ± 0.031). It was slightly lower among the six CF sites (0.89 ± 0.023) and among the six NF sites (0.89 ± 0.044), and lowest among the six SF sites (0.85 ± 0.049). It was highest between CF and AC (0.90 ± 0.026), intermediate between CF and SF sites (0.86 ± 0.038) and between SF and NF sites (0.86 ± 0.045), and lowest between AC and SF sites (0.83 ± 0.035), between AC and NF sites (0.83 ± 0.048), between CF and NF sites (0.84 ± 0.053).

Two-dimensional ordination of study sites using abundance data in a multidimensional scaling showed no overlap between habitats, although many sites of different habitats, particularly from NF, SF and CF, are closer to each other. The soil in annual croplands is also less covered by dead leaves forming the litter (Fig. VII.2.). A one-way MANOVA of the sample scores extracted from the two-dimensional ordination revealed a significant difference between the four groups of sites (Rao's $R_{6,38} = 3.43$, $P < 0.01$).

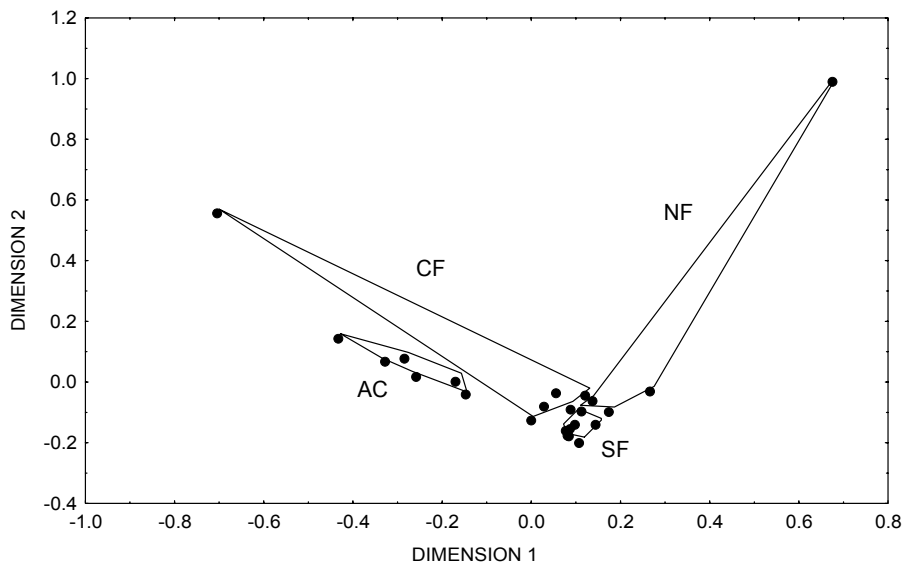


Figure VII.2.: Multidimensional scaling of invertebrate orders composition at different sampling stations based on abundance data. Sampling stations belonging to the same habitat category are connected by lines. See Fig. VII.1. for abbreviations of habitat types.

In SF, the most recorded orders were Ephemeroptera, Lepidoptera and Symphyla, all having significantly higher abundances in this habitat type compared to others. In contrast, CF was dominated by Araneida, Diplopoda, Diplura, Gasteropoda, Homoptera and Mantodea. AC was dominated by Heteroptera, Hymenoptera, Isoptera, Nematoda and Orthoptera. In NF, no insect order appeared to be dominating (see Fig. VII.3A. and Table VII.1.).

The highest average lengths of invertebrates in NF were those of Coleoptera. In SF, these were Chilopoda. In AC, largest average lengths were found in Diplura, Heteroptera, Homoptera, Mantodea, Neuroptera and Odonata. In CF, no particular insect order was found to be especially important in size (Fig. VII.3A' and Table VII.1.).

Table VII.1.: Distribution of leaf-litter invertebrate orders between habitat types according to highest abundance and average length found (only if abundance and length were respectively significantly higher in one compared to other habitat types).

Abundance				Average length			
NF	SF	CF	AC	NF	SF	CF	AC
	Ephemeroptera	Araneida Diplopoda Diplura Gasteropoda Homoptera Mantodea	Heteroptera Hymenoptera Isoptera Nematoda Orthoptera	Coleoptera	Chilopoda		Diplura Heteroptera Homoptera Mantodea Neuroptera Odonota
	Lepidoptera						
	Symphyla						

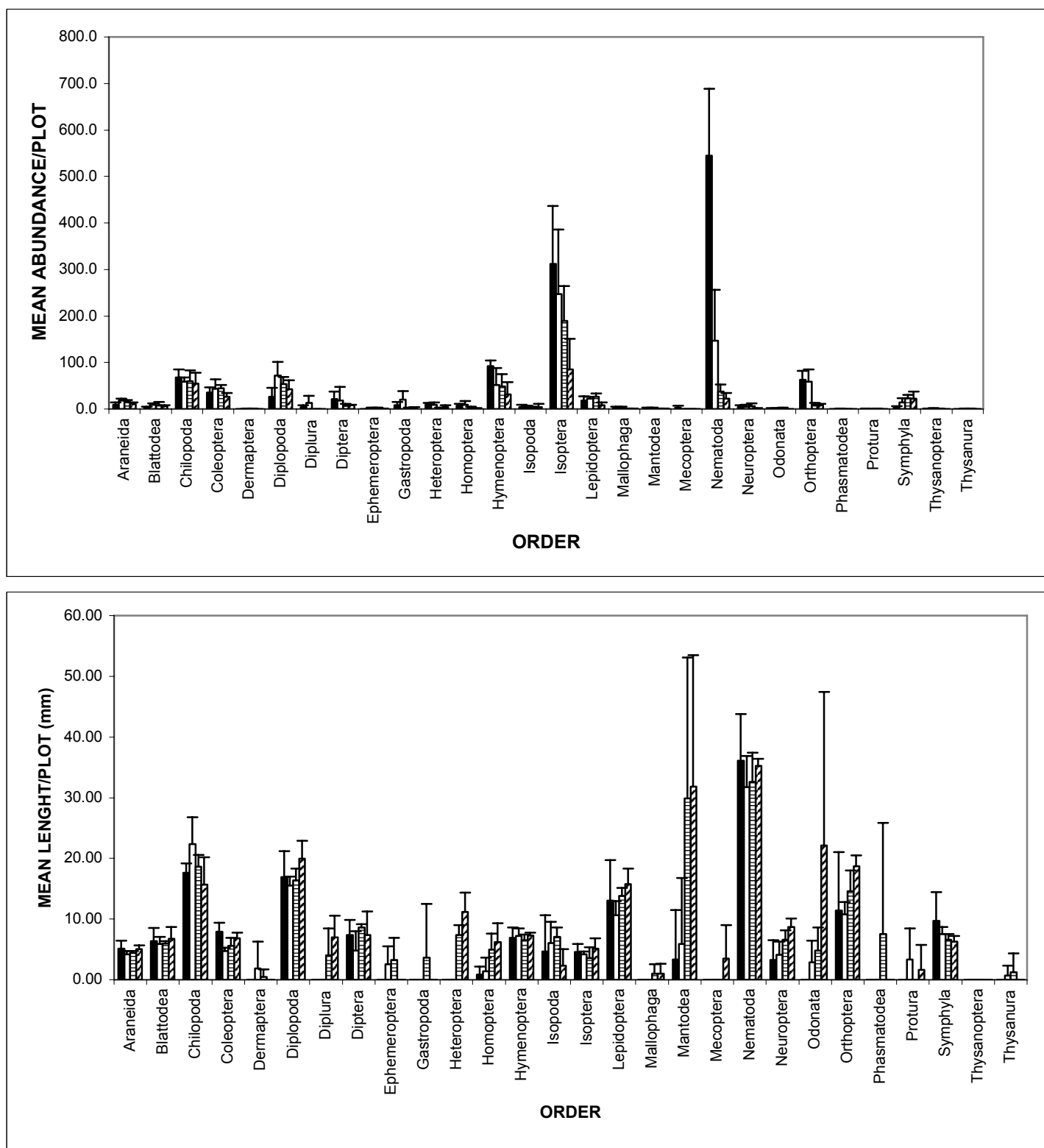


Figure VII.3.: Mean abundance (A) and mean length in millimeter (A') of invertebrate orders per plot for each habitat. The error bars are positive standard deviations. Black bars are for annual cultures; white bars for agro-forestry systems; bars with horizontal lines for secondary forests; bars with bowed lines for near primary forests.

VII.3.1.3. Invertebrate order level responses to habitat types

Out of the 28 orders recorded in the 24 sampling stations, 14 orders showed significant responses to habitat type (ANOVAs, $P < 0.05$) (see Table VII.2.). Based on ANOVA and post-hoc tests (Tukey's HSD test, $P < 0.05$), five main categories of responses were defined. In response category 1, only one order, Nematoda, was significantly more abundant in AC as compared to other habitat types. In response category 2, four orders, namely Diplura, Gasteropoda, Heteroptera and Orthoptera, were significantly more abundant in land use systems (AC and CF) as compared to natural habitats (SF and NF). In response category 3, five orders, namely Homoptera, Hymenoptera, Isoptera, Lepidoptera and Mantodea, were significantly more abundant in modified habitats (SF, CF and AC). In response category 4, only one order, namely Araneida, was significantly more abundant in CF and SF. In response category 5, three orders, namely Diplopoda, Ephemeroptera and Symphyla, were significantly less abundant in AC (see Table VII.2.).

Table VII.2.: Invertebrate orders with significant responses to habitat type. Invertebrates abundance expressed as total number of individuals recorded (n), and given for each habitat type as mean \pm S.D. of the total number of individuals recorded in each of the 24 study sites. Results of one-way ANOVA, as well as response category and preferred habitat type are also given.

Order	n	Habitats								$F_{3,20}$	$P < 0.05$	Cat.	Significant abundance in
		NF		SF		CF		AC					
		Mean	SD	Mean	SD	Mean	SD	Mean	SD				
Araneida	322	10.7	3.8	15.8	3.2	18.5	3.9	8.7	5.3	7.29	0.00172	4	CF, SF
Diplopoda	1163	42.2	19.3	53.5	15.4	71.5	29.4	26.7	18.9	4.68	0.0124	5	CF, SF, NF
Diplura	103	0.0	0.0	0.0	0.0	13.0	15.1	4.2	3.6	3.75	0.02745	2	AC, CF
Ephemeroptera	19	0.2	0.4	1.8	1.6	1.2	1.5	0.0	0.0	3.66	0.02979	5	CF, SF, NF
Gasteropoda	194	1.8	1.7	1.8	1.2	20.2	17.9	8.5	7.2	4.76	0.01155	2	AC, CF
Heteroptera	146	3.8	4.3	1.0	2.0	9.0	5.1	10.5	2.3	8.78	0.000	2	AC, CF
Homoptera	110	0.7	1.2	1.8	3.3	8.7	8.2	7.2	3.5	4.02	0.02172	3	AC, CF, SF
Hymenoptera	1335	31.0	26.8	48.3	26.1	51.5	36.7	91.7	13.0	5.43	0.00677	3	AC, CF, SF
Isoptera	4997	84.7	66.3	189.5	75.1	246.8	139.0	311.8	125.1	4.95	0.0099	3	AC, CF, SF
Lepidoptera	451	8.5	6.0	26.2	7.7	22.3	4.5	18.2	9.5	6.82	0.00239	3	AC, CF, SF
Mantodea	26	0.2	0.4	0.5	0.8	2.0	1.4	1.7	1.0	4.80	0.01118	3	AC, CF, SF

Nematoda	4511	22.5	11.8	37.7	14.7	146.7	109.1	545.0	143.1	43.76	0.000	1	AC
Orthoptera	828	7.7	3.6	9.2	4.5	58.3	26.6	62.8	18.9	19.97	0.000	2	AC, CF
Symphyla	390	22.5	14.6	23.7	6.9	14.0	9.5	4.8	1.6	5.19	0.00818	5	CF, SF, NF

Notes: See Fig. VII.1. for abbreviations of habitat types.

VII.3.2. Fruiting trees

VII.3.2.1. Density of fruiting trees

The detection probability function for fruiting trees on which birds feed can be observed in Fig.VII.4.. The table VII.3. is a compilation of distance analysis results for different habitat types.

Table VII.3.: Point estimates of fruiting trees as food resources for birds.

Habitat	EDR (m)	DP	D (Nber/ha)
NF	39.85±4.97	0.42	5.73±2.19
SF	38.10±1.90	0.29	8.35±1.54
CF	35.78±1.63	0.36	8.64±1.32
AC	39.80±1.92	0.26	7.23±1.37

Notes: Point estimates are given \pm Standard Error; EDR: Effective detection radius; DP: Detection probability; D: Density. See Fig. VII.1. for abbreviations of habitat types.

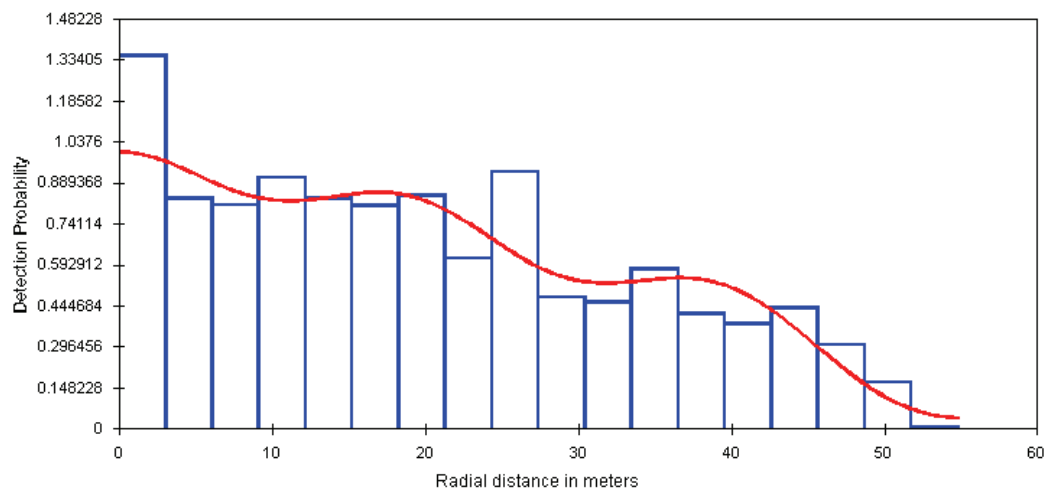


Figure VII.4.: Detection function for fruiting trees as food resources for birds.

VII.3.2.2. Species richness and abundance of fruiting trees

In the 24 study sites, a total of 764 fruiting tree records (single detections of fruiting tree individuals) belonging to 21 identified tree species were obtained (see Table VII.4.). Fruiting tree species richness was significantly affected by habitat type (One-way ANOVA, $F_{3,20}=7.14$, $P < 0.001$): Highest species richness was found in SF with a mean number of $10.2 (\pm 2.4)$ species; it was slightly lower in CF (8.8 ± 2.4) and in AC (7.8 ± 1.5), and was significantly lower in NF sites (3.7 ± 2.3 , Tukey's HSD test, $P < 0.001$) (see Fig. VII.5A.).

The number of fruiting tree records per sampling station was also significantly affected by habitat type (One-way ANOVA, $F_{3,19}=10.07$, $P < 0.01$): Highest abundance in fruiting trees was found in SF (mean \pm S.D., 39.3 ± 9.9); it was slightly lower in AC (37.2 ± 16.4) and in CF (35.3 ± 14.4), and was significantly lower in NF (8.0 ± 6.2 , Tukey's HSD test, $P < 0.01$) (see Fig. VII.5B. and Table VII.4.).

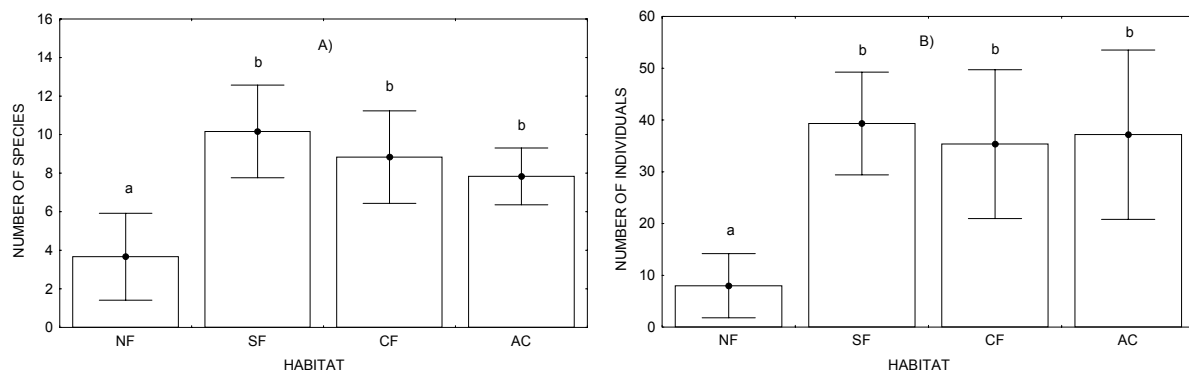


Figure VII.5.: Mean fruiting tree species richness (\pm standard deviation) (A). Beside, mean abundance (\pm standard deviation) of fruiting trees is also presented (B). Different letters indicate significant differences (Tukey's Honest Significant Difference-Test). See Fig. VII.1. for abbreviations of habitat types.

Sixteen bird families were seen feeding on fruits of fruiting trees, among which Columbidae, Pycnonotidae, Bucerotidae, Capitonidae and Nectariniidae were the most represented. Among the 21 tree species fruiting in our study area during the sampling period, *Alchornea cordifolia*, *Elaeas guineensis*, *Ficus sp.*, *Funtumia elastica* and *Musanga cecropioides*, which are known to be species abundant of degraded habitats, were found to be the most attractive for many bird families (see Table VII.4.).

Table VII.4.: Fruiting tree species and the respective abundance in different habitat types.
Bird families seen feeding on flowers/fruits are also presented.

Fruiting tree species	Habitat				Bird family
	NF	SF	CF	AC	
<i>Alchornea cordifolia</i>	0	0	0	11	Columbidae, Alcedinidae, Pycnonotidae, Nectariniidae, Estrildidae, Ploceidae
<i>Apodasmia sp.</i>	5	3	0	0	Columbidae
<i>Baïllonella toxisperma</i>	1	1	1	1	Bucerotidae, Pycnonotidae
<i>Ceiba pentandra</i>	3	3	2	1	Psittacidae
<i>Dacryodes edulis</i>	4	8	30	27	Pycnonotidae
<i>Elaeas guineensis</i>	18	55	21	87	Psittacidae, Sylviidae, Estrildidae, Pycnonotidae, Ploceidae
<i>Ficus sp.</i>	4	12	12	4	Columbidae, Picidae, Oriolidae
<i>Funtumia elastica</i>	1	5	39	3	Capitonidae, Nectariniidae, Pycnonotidae
<i>Mangifera indica</i>	0	0	5	8	Estrildidae
<i>Musanga cecropioides</i>	11	9	20	19	Bucerotidae, Capitonidae, Pycnonotidae, Nectariniidae
<i>Percea sp.</i>	0	1	5	5	Pycnonotidae
<i>Picnanthus angolensis</i>	41	78	9	1	Capitonidae, Psittacidae
<i>Pterocarpus soyauxii</i>	0	4	0	1	Psittacidae
<i>Raphia sp.</i>	0	3	0	0	Bucerotidae, Pycnonotidae
<i>Ricinodendron heudoletii</i>	3	14	7	36	Bucerotidae, Musophagidae
<i>Rovolfia vomitoria</i>	0	15	36	5	Nectariniidae
<i>Terminalia ivorensis</i>	0	1	2	0	Psittacidae
<i>Terminalia superba</i>	0	10	5	0	Sturnidae
<i>Theobroma cacao</i>	0	4	0	1	Nectariniidae
<i>Xylopia aethiopica</i>	2	9	18	12	Bucerotidae, Nectariniidae
<i>Unknown</i>	0	1	0	0	Nectariniidae
Total	93	236	212	223	

Notes: See Fig. VII.1. for abbreviations of habitat types.

VII.3.3. Flowering trees

VII.3.3.1. Density of flowering trees

The detection probability function for flowering trees on which birds feed can be observed in Fig.VII.6.. The table VII.5. is a compilation of distance analysis results of different habitat types.

Table VII.5.: Point estimates of flowering trees as food resources for birds.

Habitat	EDR (m)	DP	D (ha)
NF	41.81±6.65	0.72	3.85±1.45
SF	45.60±5.42	0.71	3.20±0.91
CF	34.73±2.20	0.31	11.04±2.53
AC	49.99±6.47	0.32	3.26±1.5

Notes: Point estimates are given \pm Standard Error; EDR: Effective detection radius; DP: Detection probability; D: Density. See Fig. VII.1. for abbreviations of habitat types.

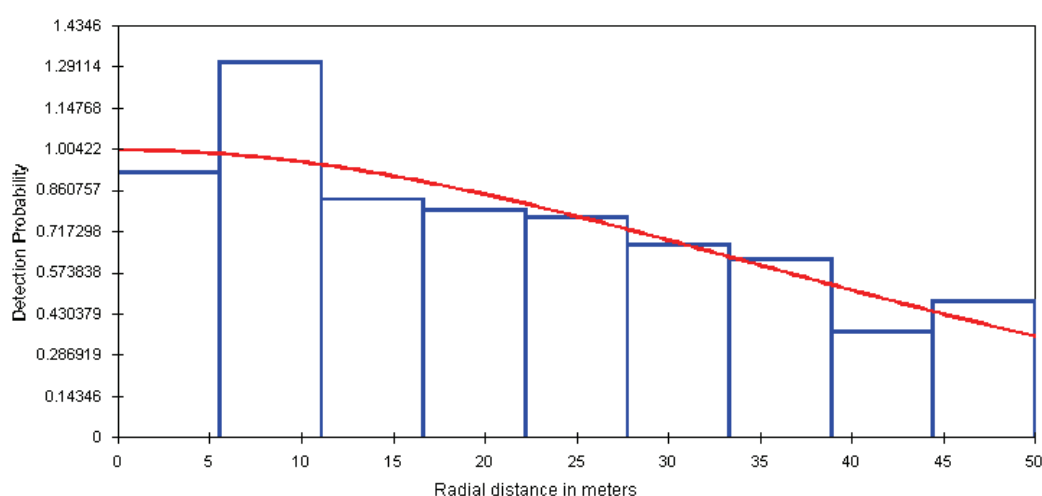


Figure VII.6.: Detection function for flowering trees as food resources for birds.

VII.3.3.2. Species richness and abundance of flowering trees

In the 24 study sites, a total of 219 flowering tree records (single detections of flowering tree individuals) belonging to seven identified tree species were obtained (see Table VII.6.). Flowering tree species richness was significantly affected by habitat type (One-way ANOVA, $F_{3,20} = 9.44$, $P < 0.001$): Highest species richness was found in SF with a mean number of 3.5 (± 0.8) species; it was slightly lower in CF (3.3 ± 0.5), and was significantly lower in AC (2.3 ± 0.5) (Tukey's HSD test, $P < 0.01$) and in NF sites (1.7 ± 0.8) (Tukey's HSD test, $P < 0.05$) (see Fig. VII.7A.).

The number of flowering tree records per sampling station was also significantly affected by habitat type (One-way ANOVA, $F_{3,19} = 5.24$, $P < 0.01$): Highest abundance in flowering trees was found in CF (mean \pm S.D., 18.8 ± 12.2); it was lower in SF (7.7 ± 3.5), and was

significantly lower in AC (6.8 ± 6.6 , Tukey's HSD test, $P < 0.05$) and in NF sites (3.2 ± 1.8 , Tukey's HSD test, $P < 0.01$) (see Fig. VII.7B. and Table VII.6.).

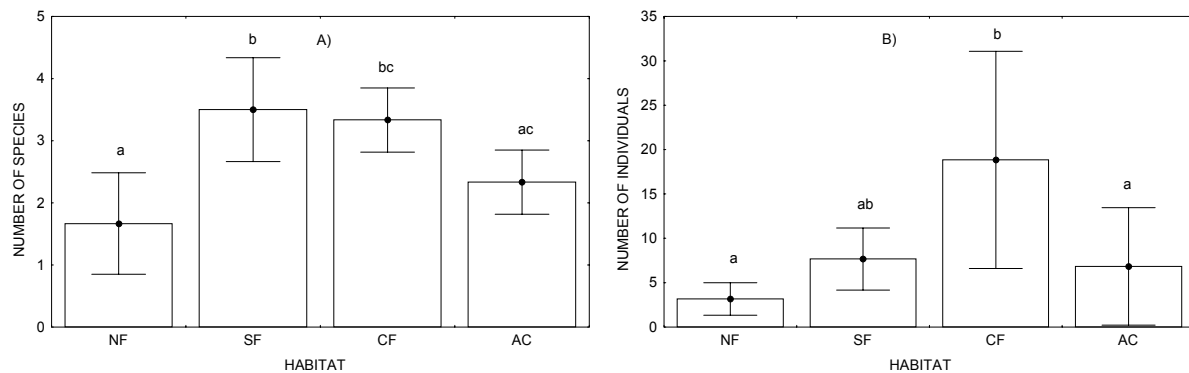


Figure VII.7.: Mean flowering tree species richness (\pm standard deviation) (A). Beside, mean abundance (\pm standard deviation) of flowering trees is also presented (B). Different letters indicate significant differences (Tukey's Honest Significant Difference-Test). See Fig. VII.1. for abbreviations of habitat types.

Five bird families were seen feeding on fruits/flowers of flowering trees, namely Columbidae, Bucerotidae, Capitonidae, Pycnonotidae and Nectariniidae. Among the seven tree species flowering during the sampling period, *Funtumia elastica* and *Musanga cecropioides* were found to be the most attractive for many bird families (see Table VII.6.).

Table VII.6.: Flowering tree species and abundance in different habitat types. Corresponding bird families seen feeding on flowers/fruits are also presented.

Flowering tree species	Habitat				Bird family
	NF	SF	CF	AC	
<i>Apodasmia sp.</i>	5	3	0	0	Nectariniidae, Columbidae
<i>Funtumia elastica</i>	1	5	39	3	Nectariniidae, Capitonidae, Pycnonotidae
<i>Musanga cecropioides</i>	11	9	20	19	Nectariniidae, Capitonidae, Pycnonotidae
<i>Rovolfia vomitoria</i>	0	15	36	5	Nectariniidae
<i>Theobroma cacao</i>	0	4	0	1	Nectariniidae
<i>Xylopia aethiopica</i>	2	9	18	12	Nectariniidae, Bucerotidae
<i>Unknown</i>	0	1	0	1	Nectariniidae
Total	19	46	113	41	

Notes: See Fig. VII.1. for abbreviations of habitat types.

VII.3.4. Leaf-litter area and weight

A total of 1,920 leaves, belonging to 96 tree species, were collected. Overall mean leaf area and weight per sampling station were significantly affected by habitat types (One-way ANOVA, for leaf area: $F_{3,20} = 10.39$, $P < 0.001$; for leaf weight: $F_{3,20} = 19.21$, $P < 0.0019$).

As predicted, overall leaf area (cm^2) was highest in CF (mean \pm SD; 150.98 ± 18.58) and SF (150.32 ± 23.44); it was slightly lower in NF (126.08 ± 30.78) and, was significantly lower in AC (89.94 ± 7.77 ; Tukey's Honest Significant Difference-Test, $P < 0.001$) (see Fig. VII.8A., Appendix VII.1.). Among the 96 tree species with common leaves, four showed nearly or significant difference in leaf area between habitat types (One-way ANOVA for: *Barteria fistulosa*, $F_{2,4} = 45.04$, $P = 0.0018$; for *Cola nitida*, $F_{2,5} = 5.78$, $P = 0.0502$; for *Musanga cecropioides*, $F_{3,4} = 5.47$, $P = 0.067$; and for *Terminalia superba*, $F_{3,7} = 3.66$, $P = 0.072$) (see Appendix VII.1.).

Overall leaf weight (g) was highest in SF (mean \pm SD; 3.30 ± 0.58); it was slightly lower in NF (2.92 ± 0.82), and was significantly lower in CF (1.81 ± 0.18 ; Tukey's Honest Significant Difference-Test, $P < 0.001$) and in AC (1.30 ± 0.24 ; Tukey's Honest Significant Difference-Test, $P < 0.001$) (see Fig. VII.8B., Appendix VII.2.). But, does this 2 g leaf weight difference between SF and AC really matter too much? Among the 96 tree species with common leaves, six showed nearly or significant difference in leaf weight between habitat types (One-way ANOVA for: *Baphia nitida*, $F_{2,6} = 4.31$, $P = 0.069$; for *Barteria fistulosa*, $F_{2,4} = 10.14$, $P = 0.027$; for *Coffea robusta*, $F_{2,5} = 4.73$, $P = 0.07$; for *Cola nitida*, $F_{2,5} = 22.98$, $P = 0.003$; for *Irvingia gabonensis*, $F_{1,5} = 4.87$, $P = 0.078$; and for *Musanga cecropioides*, $F_{3,4} = 5.29$, $P = 0.071$) (see Appendix VII.2.).

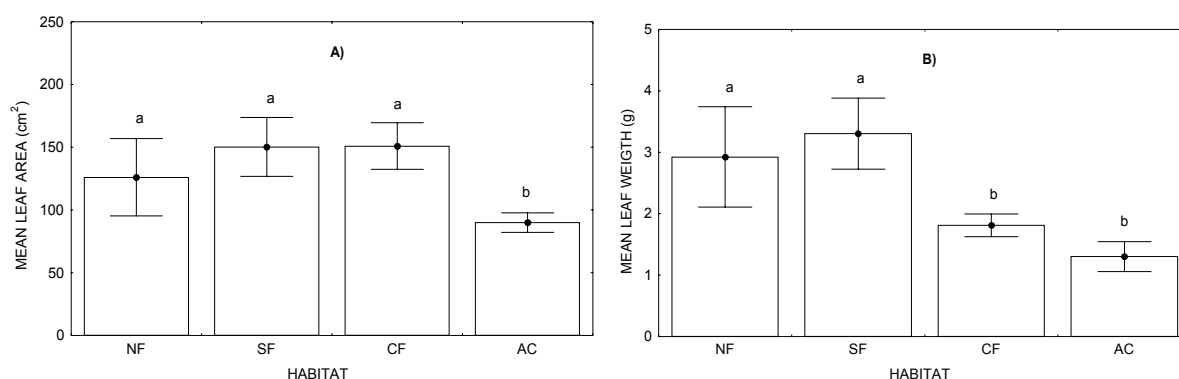


Figure VII.8.: Mean leaf area A) and mean leaf weight B) per sampling station; Error bars indicate \pm standard deviation; Different letters indicate significant differences (Tukey's Honest Significant Difference-Test). See Fig. VII.1. for abbreviations of habitat types.

VII.3.5. Understorey bird species richness and abundance

In the 24 sites, a total of 1,307 understorey bird records (single detections of understorey bird individuals) belonging to 93 identified species were obtained. At each study site, highest overall understorey bird observed species richness was found in AC with a mean number of $22.3 (\pm 6.2)$ species; it was slightly lower in SF (19.7 ± 2.1) and in CF (17.3 ± 3.2), and was significantly lower in NF (16.0 ± 1.8) (One-way ANOVA, $F_{3,20} = 3.29$, $P < 0.05$) (see Fig. VII.9A.). The number of understorey bird records per sampling station was not significantly affected by habitat type (One-way ANOVA, $F_{3,20} = 0.65$, $P = 0.59$) (see Fig. VII.9A').

Overall understorey insectivorous birds did not show significant difference in species richness and abundance between habitat types (One-way ANOVA, for species richness: $F_{3,20} = 0.66$, $P = 0.08$, see Fig. VII.9B.; for abundance: $F_{3,20} = 2.96$, $P = 0.06$, see Fig. VII.9B').

Highest understorey ant-following bird species richness was found in SF with a mean number of $6.5 (\pm 1.43)$ species; it was slightly lower in NF (5.3 ± 1.0) and was significantly lower in CF (3.5 ± 1.6) and in AC (1.3 ± 0.5) (One-way ANOVA, $F_{3,20} = 20.60$, $P < 0.001$) (see Fig. VII.9C.). Highest number of understorey ant-following bird individuals was found in NF (21.2 ± 7.4) and SF (21.0 ± 5.9); it was significantly lower in CF (6.3 ± 3.6) and AC (1.7 ± 0.8) (One-way ANOVA, $F_{3,20} = 23.49$, $P < 0.001$) (see Fig. VII.9C').

Understorey large-sized foliage gleaners did not show significant difference in species richness and abundance between habitat types (One-way ANOVA, for species richness: $F_{3,20} = 0.55$, $P = 0.66$, see Fig. VII.9D.; for abundance: $F_{3,20} = 0.69$, $P = 0.57$, see Fig. VII.9D').

Highest understorey medium-sized foliage gleaner bird species richness was found in SF with a mean number of $7.8 (\pm 1.2)$ species; it was slightly lower in NF (6.5 ± 0.5) and was significantly lower in CF (4.3 ± 1.4) and in AC (3.8 ± 2.1) (One-way ANOVA, $F_{3,20} = 10.39$, $P < 0.001$) (see Fig. VII.9E.). Highest number of understorey medium-sized foliage gleaner bird individuals was found in NF (22.5 ± 9.2); it was slightly lower in SF (19.0 ± 5.8) and was significantly lower in CF (6.2 ± 2.6) and AC (6.5 ± 3.9) (One-way ANOVA, $F_{3,20} = 12.16$, $P < 0.001$) (see Fig. VII.9E').

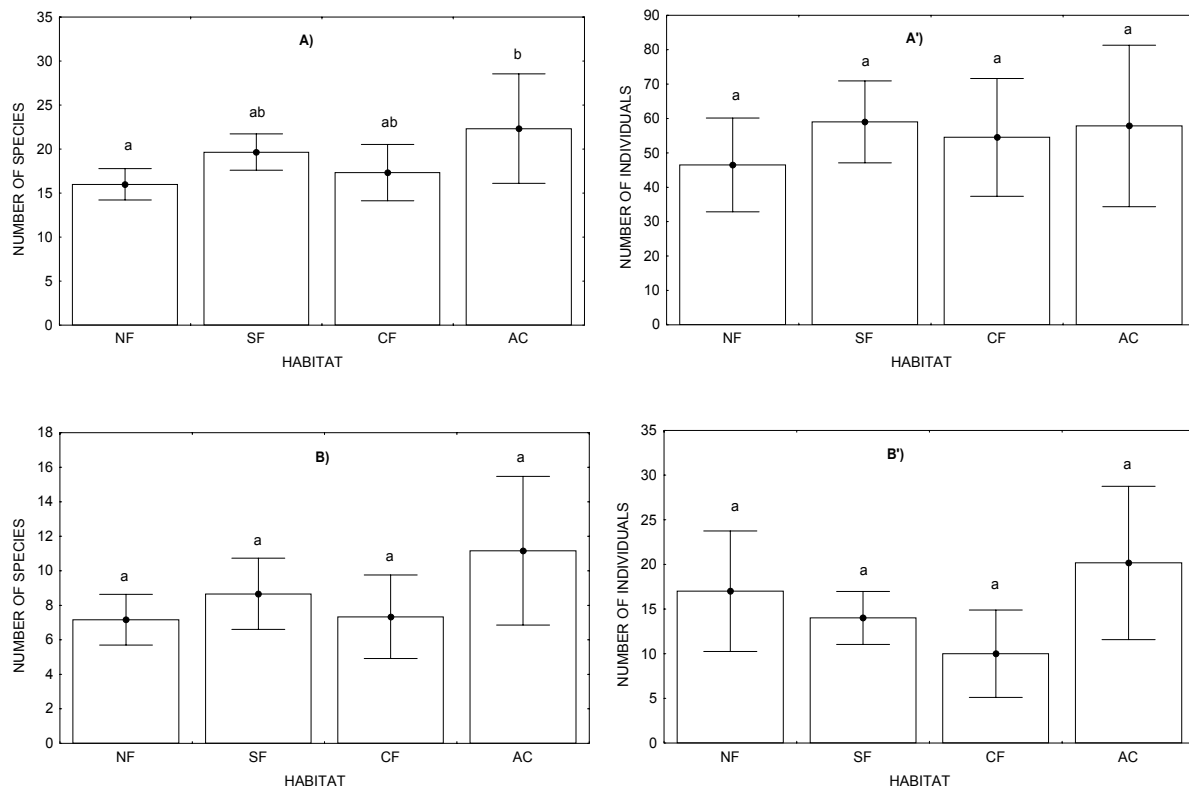
Understorey small-sized foliage gleaners did not show significant difference in species richness and abundance between habitat types (One-way ANOVA, for species richness: $F_{3,20} = 1.99$, $P = 0.15$, see Fig. VII.9F.; for abundance: $F_{3,20} = 1.02$, $P = 0.41$, see Fig. VII.9F').

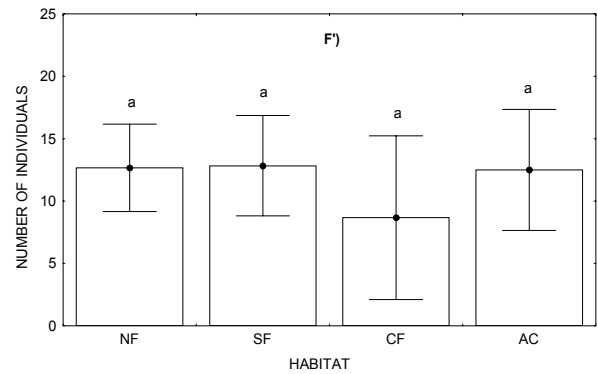
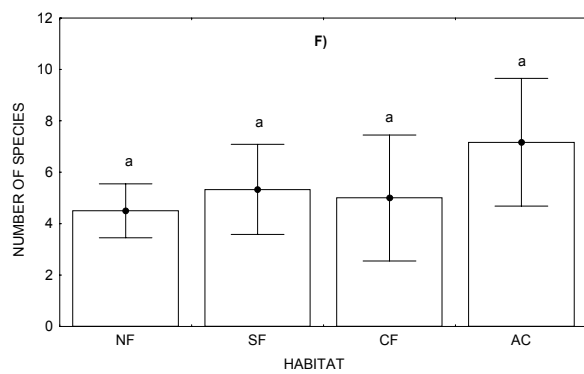
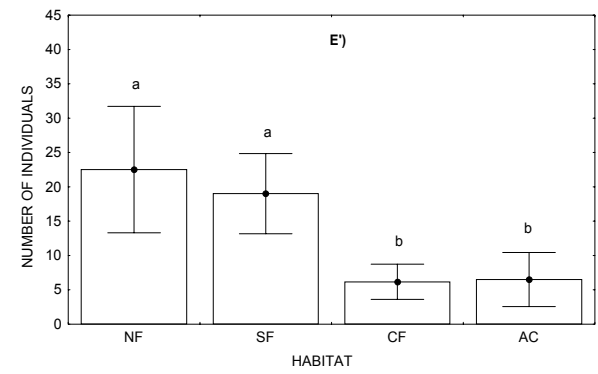
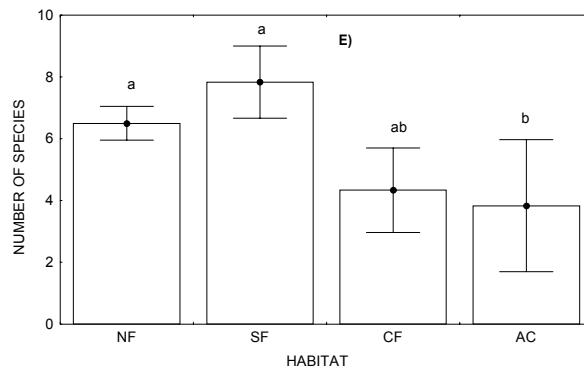
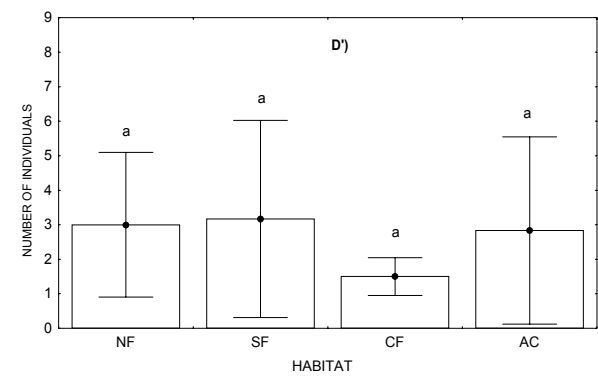
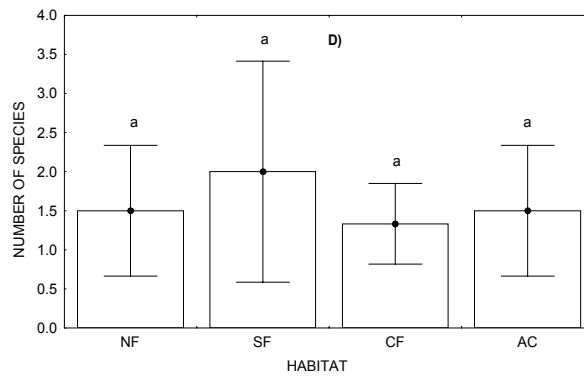
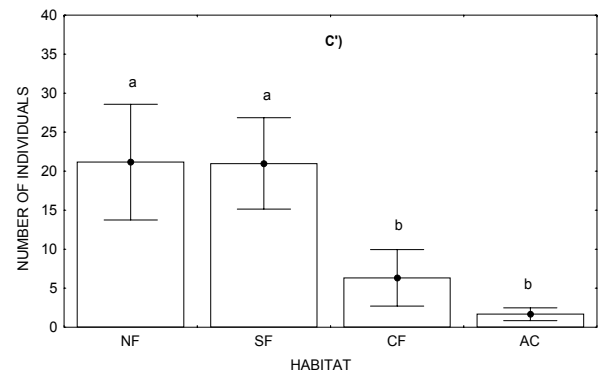
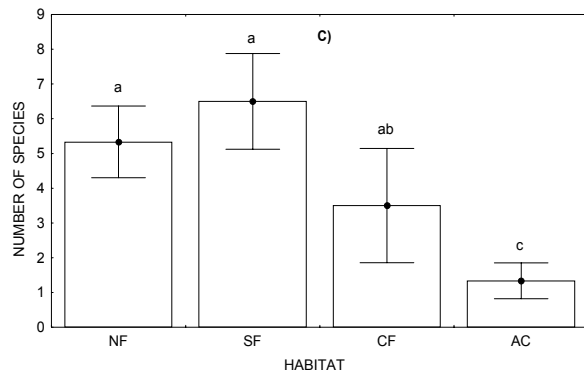
Understorey frugivores did not show significant difference in species richness and abundance between habitat types (One-way ANOVA, for species richness: $F_{3,20} = 2.75$, $P = 0.07$, see Fig. VII.9G.; for abundance: $F_{3,20} = 2.22$, $P = 0.12$, see Fig. VII.9G').

Highest understorey nectarivorous bird species richness was found in AC with a mean number of $3.7 (\pm 1.2)$ species; it was significantly gradually lower in CF (2.0 ± 0.6), SF (1.3 ± 0.5) and in NF (1.0 ± 0.0) (One-way ANOVA, $F_{3,20} = 15.83$, $P < 0.001$) (see Fig. VII.9H.). Highest number of understorey nectarivorous bird individuals was found in CF (13.0 ± 2.8); it was slightly lower in AC (12.0 ± 5.2) and SF (7.3 ± 3.6), and was significantly lower in NF (4.0 ± 2.7) (One-way ANOVA, $F_{3,20} = 7.78$, $P < 0.01$) (see Fig. VII.9H').

Highest understorey omnivorous bird species richness was found in AC with a mean number of $2.7 (\pm 1.0)$ species; it was slightly lower in CF (2.2 ± 0.4), SF (2.0 ± 0.6), and was significantly lower in NF (1.2 ± 0.98) (One-way ANOVA, $F_{3,20} = 3.59$, $P < 0.05$) (see Fig. VII.9I.). Highest number of understorey omnivorous bird individuals was found in CF (22.2 ± 10.8); it was slightly lower in SF (15.0 ± 7.9) and AC (12.7 ± 7.6), and was significantly lower in NF (3.0 ± 2.6) (One-way ANOVA, $F_{3,20} = 6.15$, $P < 0.01$) (see Fig. VII.9I').

Understorey pycnonotids did not show significant difference in species richness and abundance between habitat types (One-way ANOVA, for species richness: $F_{3,20} = 0.87$, $P = 0.47$, see Fig. VII.9J.; for abundance: $F_{3,20} = 2.31$, $P = 0.11$, see Fig. VII.9J').





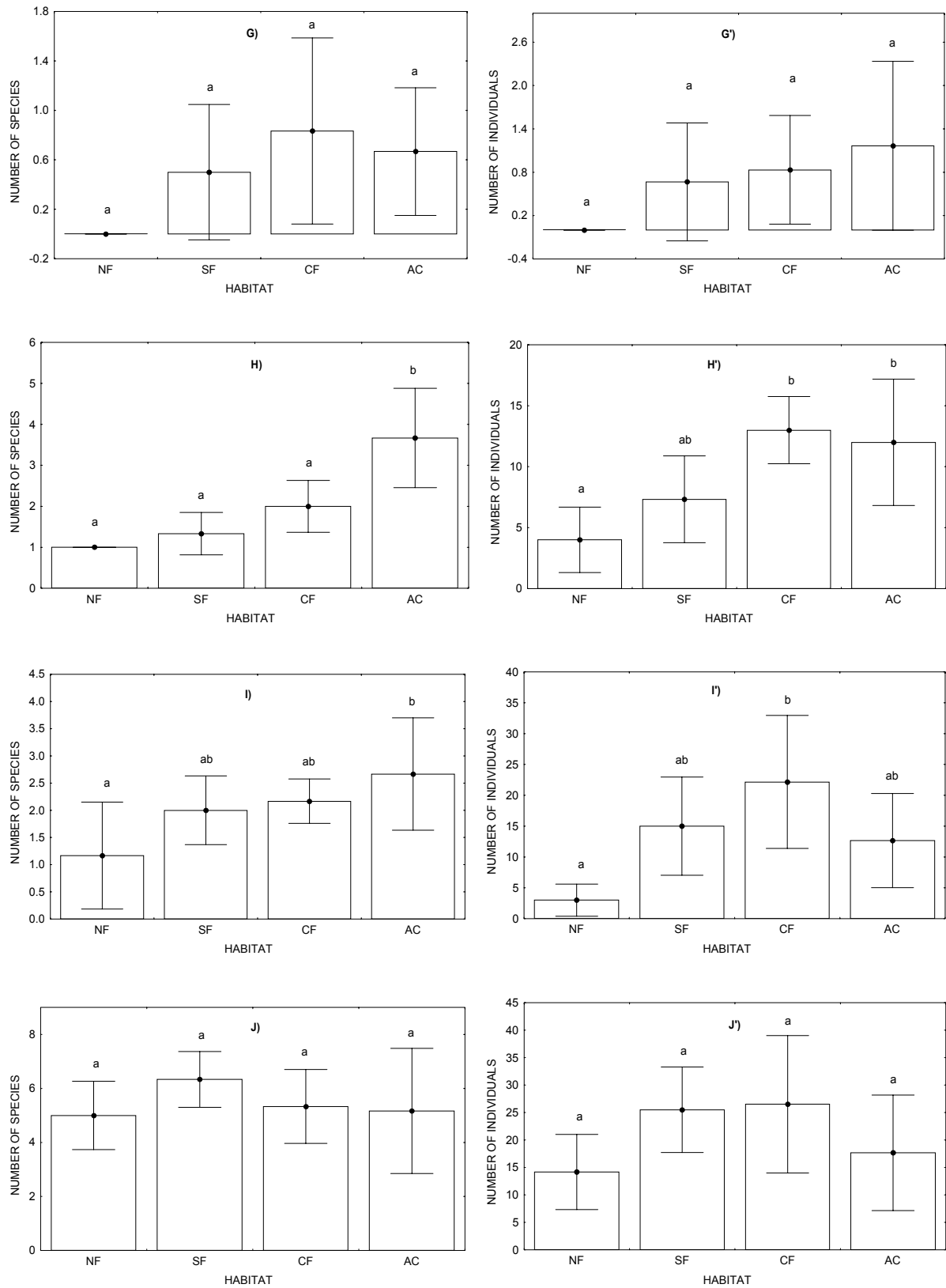


Figure VII.9.: Mean species richness and mean abundance (\pm standard deviation) given as observed number of recorded understorey bird species and individuals, for all bird species detected (A) and for all individuals detected (A'), for overall insectivores (B and B'), ant-followers (C and C'), large-sized foliage gleaners (D and D'), medium-sized foliage gleaners

(E and E'), small-sized foliage gleaners (F and F'), frugivores (G and G'), nectarivores (H and H'), omnivores (I and I') and Pycnonotidae (J and J'). Different letters indicate significant differences (Tukey's Honest Significant Difference-Test) between mean observed species richness and mean abundance. See Fig. VII.1. for abbreviations of habitats.

VII.3.6. Correlations between understorey bird and leaf-litter invertebrate parameters

Out of the 156 Spearman rank correlations between understorey bird species richness and abundance and invertebrate order richness and abundance, 42 were significant on the 5% level. After applying the Bonferroni correction to this list, just 10 are still significant on the 5% level (see Table VII.7.). Overall invertebrate abundance was strongly negatively correlated with ant-following and medium-sized foliage gleaner bird species richness and abundance. Among the 11 studied invertebrate groups with more than 250 individuals each, just the Nematoda and Orthoptera showed significant correlations with some understorey insectivorous bird groups studied after the Bonferroni correction: Nematoda was strongly negatively correlated with ant-following bird species richness and abundance. Orthoptera was strongly negatively correlated with ant-following and medium-sized foliage gleaner bird species richness and abundance.

VII.3.7. Correlations between fruiting and flowering trees and the studied bird feeding guilds/groups

Out of the 40 Spearman rank correlations between the studied groups of understorey bird species richness and abundance, and the fruiting and flowering tree species richness and abundance, 16 were significant on the 5% level (see Table VII.8.). Fruiting tree species richness was moderately positively correlated with abundance of overall understorey birds, Nectariniidae and Pycnonotidae, as well as with species richness and abundance of omnivorous birds. Fruiting tree abundance was moderately positively correlated with abundance of Nectariniidae and Pycnonotidae, as well as with species richness and abundance of frugivorous and omnivorous birds. Flowering tree species richness was moderately positively correlated with abundance of Nectariniidae and omnivorous birds. Flowering tree abundance was moderately positively correlated with frugivorous bird species richness, as well as with abundance of Pycnonotidae and omnivorous birds.

Table VII.7.: Spearman rank correlation coefficients r_s of relationships between overall understorey bird species richness and abundance, as well as for different groups of understorey insectivores studied, and overall invertebrate order richness and abundance, as well as for abundance of different invertebrate orders that are more than 250 individuals.

Observed understorey birds	Invertebrate parameters												
	Observed+	Overall++	Araneida++	Chilopoda++	Coleoptera++	Diplopoda++	Diptera++Hymenoptera++	Isoptera++	Lepidoptera++	Nematoda++	Orthoptera++	Symphyla++	
Overall+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Overall++	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Overall insectivores+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Overall insectivores++	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Ant-following+	n.s.	-0.7783***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.7553***	-0.6735***	n.s.	
Ant-following++	n.s.	-0.8047***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.704***	-0.8148***	n.s.	
Large-sized foliage gleaner+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Large-sized foliage gleaner++	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Medium-sized foliage gleaner+	n.s.	-0.644*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.648*	n.s.	
Medium-sized foliage gleaner++	n.s.	-0.7309***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.709***	n.s.	
Small-sized foliage gleaner+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Small-sized foliage gleaner++	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	

Notes: Bonferroni corrected table-wide significance level α * ≤ 0.05 , ** ≤ 0.001 . In bold are significance on the 5% level before the Bonferroni correction; +: Species richness for understorey birds / order richness for invertebrates; ++: Abundance.

Table VII.8.: Spearman rank correlation coefficients r_s of correlations between the fruiting and flowering tree species richness and abundance and the studied bird groups/guilds species richness and abundance.

Birds groups/guilds	Food resources for birds			
	Fruiting trees		Flowering trees	
	+	++	+	++
Overall understorey birds+	n.s.	n.s.	n.s.	n.s.
Overall understorey birds++	0.4558*	n.s.	n.s.	n.s.
Understorey frugivores+	n.s.	0.4577*	n.s.	0.5826**
Understorey frugivores++	n.s.	0.4782*	n.s.	n.s.
Understorey nectarivores+	n.s.	n.s.	n.s.	n.s.
Understorey nectarivores++	0.4845*	0.4595*	0.4521*	n.s.
Understorey omnivores+	0.4698*	0.4875*	n.s.	n.s.
Understorey omnivores++	0.6852***	0.5987**	0.5454**	0.5952**
Understorey Pycnonotidae+	n.s.	n.s.	n.s.	n.s.
Understorey Pycnonotidae++	0.5934**	0.5149*	n.s.	0.4763*

Notes: *: significance on the 5% level; **: significance on the 1% level; ***: significance on the 0.1% level; +: Observed species richness; ++: Abundance.

VII.3.8 Correlation between leaf-litter area and weight, and ground foraging birds

As forest francolins were not part of our mist-netted community, abundance of medium to large ground foraging birds, namely two pycnonotids of the genus *Bleda* (Red-tailed Bristlebill *Bleda syndactyla* and Lesser Bristlebill *B. notata*), six thrushes (Blue-shouldered Robin Chat *Cossypha cyanocampter*, Fire-crested Alethe *Alethe diademata*, Brown-chested Alethe *A. poliocephala*, White-tailed Ant Thrush *Neocossyphus poensis*, Rufous Flycatcher Thrush *Stizorhina fraseri*, Grey Ground Thrush *Zoothera princei*) and three Babblers of the genus *Illadopsis* (Pale-breasted *Illadopsis* *Illadopsis rufipennis*, Brown *Illadopsis* *I. fulvescens*, Blackcap *Illadopsis* *I. cleaveri*) was compared with leaf area and weight.

The correlations between the leaf area and the bird groups of ground foraging thrushes or the *Bleda* spp. or all the ground foraging birds studied were positive, almost significant and moderate (in all cases, $p > [0.055; 0.076]$); the relationship between the leaf area and the bird group of *Illadopsis* was positive, weak and insignificant (see Table VII.9).

The correlations between the leaf weight and the abundance of the respective ground foraging bird groups studied were all positive, significant and strong (in all cases, $p < 0.001$) (see Table VII.9).

Table VII.9.: Spearman-rank correlation coefficient between leaf-litter area and weight, and the abundance of ground foraging birds.

Parameters	<i>R</i>	<i>t</i> (N-2)	<i>p</i>
Leaf area & Ground thrushes (6 spp.)	0.369679	1.866148	0.075409
Leaf area & Illadopsis (3 spp.)	0.272941	1.330732	0.196906
Leaf area & Bleda (2 spp.)	0.374469	1.89424	0.071415
Leaf area & All ground Foraging birds	0.395554	2.020061	0.055719
Leaf weight & Ground thrushes (6 spp.)***	0.693913	4.520104	0.000169
Leaf weight & Illadopsis (3 spp.)**	0.675144	4.292761	0.000295
Leaf weight & Bleda (2 spp.)**	0.685721	4.418842	0.000217
Leaf weight & All ground Foraging birds***	0.723074	4.909754	6.56E-05

Notes: N = 24 in all cases; Significant difference ** for $p < 0.01$ and *** for $p < 0.001$; In bold are significant relationships.

VII.4. Discussions

VII.4.1. Leaf-litter invertebrates as feeding resources for birds

Contrary to our prediction, we found that invertebrate order richness, abundance and average length showed clear increasing patterns with increasing habitat disturbance. Different invertebrate orders responded in different ways to habitat modifications and invertebrate orders composition changed along the habitat gradient. All orders found in near-primary forest were also found in modified habitats, but the opposite was not true, particularly as far as Dermaptera, Diplura, Mecoptera, Odonata, Phasmatodea, Protura, Thysanoptera and Thysanura are concerned. This means that leaf-litter of disturbed habitats can support an assemblage of invertebrate orders even more important than that found in undisturbed ones. In other words, invertebrates as food resources for understorey birds, particularly for insectivores, were significantly less abundant in natural than in degraded forests. Similarly in Las Cruces Forest, southern Costa Rica, overall numbers of invertebrate individuals per sample was about 15% lower in the extensive forest than in small fragment samples, but the difference was not significant (Şekercioğlu *et al.* 2002). But, a previous study on fruit feeding

butterflies (Lepidoptera) on our study sites two years ago indicated lowest species richness and abundance in annual croplands (Bobo *et al.* 2006b). Different results were also found in a Malaysian dipterocarp forest at Pasoh Forest Reserve (Negeri Sembilan, Peninsular Malaysia) where arthropods were less abundant in the regenerating than in the virgin forest (Wong 1986).

Like Heteroptera, Isoptera, Nematoda and Orthoptera, the ants order (Hymenoptera) showed significantly higher abundance in annual croplands as compared to other habitat types in our study area. Comparatively, selective logging did not significantly affect the overall abundance of ants in the forest floor of a central Amazonian forest (Vasconcelos *et al.* 2000), but army ants were affected and disappear when humans cut Neotropical forests (Willis & Oniki 1978).

Strong and negative correlations were found between ant-following bird species richness and abundance and the overall invertebrate abundance, as well as the Nematoda and Orthoptera order abundances in our study case. Most of other correlations between the studied bird group species richness and abundance and the abundance of invertebrate orders were insignificant, even between the Hymenoptera order and ant-following birds. Similarly in Panama, a clear relationship could not be found between the abundances of understory arthropods and understory insectivorous birds (Karr and Brawn 1990). A different situation was obtained in the Neotropical forests where army ants and ant-following birds are strongly linked and disappear almost simultaneously when the forests are cut (Willis & Oniki 1978). Although the difference in invertebrate abundance between small fragments and extensive Las Cruces forest was insignificant, abundance and species richness of understory insectivorous birds were significantly lower in small fragments (Şekercioğlu 2002).

VII.4.2. Fruiting and flowering trees as feeding resources for birds

Different from our hypothesis, although no clearly defined patterns were observed in fruiting and flowering tree species richness and abundance, near-primary forest showed significantly lowest values as compared to other habitat types. Similarly in the New Britain PNG situated off the east coast of mainland of Papua New Guinea, logged forest and forest gardens were found to have highest densities of fruiting and flowering trees compared to primary forest (Marsden & Pilgrim 2003). Different results were obtained in the studies at Pasoh Forest Reserve (Negeri Sembilan, Peninsular Malaysia) where flowers and fruits were less abundant in the regenerating than in the virgin forest (Wong 1986). In our study area, five fruiting tree species known to invade degraded habitats, namely *Alchornea cordifolia*, *Elaeas guineensis*,

Ficus sp., *Funtumia elastica* and *Musanga cecropioides*, were found to be the most attractive for many bird families, particularly Columbidae, Pycnonotidae, Bucerotidae, Capitonidae and Nectariniidae. Also, two flowering tree species invading secondary habitats, namely *Funtumia elastica* and *Musanga cecropioides* were found to be the most attractive particularly for the Nectariniidae bird family.

All significant correlations found between fruiting and flowering trees, and the studied bird groups/guilds parameters were moderate and positive, indicating that there are many understorey birds that use trees for fruits and flowers, most of which were found in land use habitats during the sampling period. This might explain the persistence of some bird species in modified habitats. It was almost the same situation in the New Britain in Papua New Guinea where antropogenic habitats have allowed large populations of parrots and hornbills to persist due to increase availability of fruiting/flowering trees (Marsden & Pilgrim 2003). In a Malaysian dipterocarp forest, fewer bird species and abundance are supported by the regenerating forest than by the virgin forest understory and was attributed to lower level of food resources in the first forest type (Wong 1986). But, it should also be considered the temporal and spatial variation in the abundance of fruits and flowers known to have particular effects on the distribution, dispersal and movements of the frugivorous/nectarivorous birds (e.g. Wong 1986, Kinnaird *et al.* 1996).

VII.4.3. Leaf-litter area and weight

As predicted, overall mean leaf area and weight were significantly affected by habitat types; intermediate (agroforestry and secondary forest) or sub-optimal habitats showed highest leaf area than near-primary forest (optimal habitat) and annual cropland (less optimal). Natural habitats showed highest leaf weight than land use systems as the results of the influence of large light dry cocoa/coffee leaves in the agroforestry systems. While the relationships between the leaf area and the respective ground foraging bird groups studied were all positive, weak to moderate and insignificant to nearly significant, the leaf weight and the respective ground foraging bird groups studied were all positively, strong and significantly correlated. It is thus clear that larger leaves did not affect negatively the presence of ground foraging bird individuals in secondary forest habitats, and there is no evidence that this group of birds has problem in turning larger leaves in order to search for food under the leaf-litter of the secondary forest floor.

VII.5. Conclusion

In conclusion, the reasons for the higher abundance of some insectivores (e.g. ant-following birds) in natural habitats might not be directly related with the parameters we studied and could suggest that a different approach to assess ground-living insects has to be used. However, the higher abundance of flowering and fruiting trees in land use systems might largely explain, at least temporally, the occurrence of several understorey forest birds in modified habitats. This temporal or seasonal dynamic of birds, motivated by the availability of food resources, is also known from Mt. Kinabalu forest in Borneo (Kimura *et al.* 2001). Therefore, the food scarcity hypothesis (Ford *et al.* 1996, Burke & Nol 1998, Zarette *et al.* 2000) might explain at least partly the patterns of diversity and abundance of several understorey bird groups, especially for frugivores and nectarivores (read also Marsden & Pilgrim 2003). Patterns of some understorey bird groups like ant-following and medium-sized foliage gleaner birds, and to some extent Pycnonotids, are probably more complex and other factors such as microclimate might play a more significant role (Karr & Freeman 1983, Karr & Brawn 1990, Stratford & Stouffer 1999, see also the habitat specificity hypothesis of Ford *et al.* (1996), Stratford & Stouffer (1999), or the limited dispersal hypothesis of Greenberg (1988), Canaday (1996), Şekercioğlu (2002), or a combination of hypotheses of Karr et Brawn (1990). Furthermore, larger leaves of the secondary forest floor were found to have no particular negative effect on the presence of ground foraging birds.

VIII

BODY WEIGHT, PARASITE LOADS, FAULT BARS, FLUCTUATING ASYMMETRY AND ADULT TERRITORY OWNERS ALONG A GRADIENT OF FOREST CONVERSION

Abstract

This chapter aimed at assessing indicators of habitat quality such as indices of parasitism, fluctuating asymmetry, occurrence of fault bars, body mass and proportion of territory owners/sedentary birds. Mist-netted birds were checked for body parasites, fault bars on wings and classic biometrical measures were also taken. Recaptures were sorted from the overall mist-netting captures. Average understorey bird body weight across species was significantly affected by habitat types and showed a clear decreasing pattern with increasing habitat modification. The Olive Sunbird showed a significantly higher average body weight in near-primary forest compared to the other habitat types, while average body weight of Little Greenbul and Yellow-whiskered Greenbul did not differ between habitat types. The number of individuals and species infested with ectoparasites, as well as their proportion, was not significantly affected by habitat types. Nonetheless, natural habitats showed highest numbers of individuals and species infested and their proportion than land use habitats. All correlations between parameters associated with parasitism (such as numbers of species and individuals infested) and overall understorey bird species richness and abundance were very weak and insignificant. Bird species and individuals presenting fault bars, as well as their proportion per sampling station, was significantly affected by habitat types, showing a clearly increasing pattern with increasing habitat modification. Overall tarsus asymmetry, as well as for the three most abundant species and for insectivorous birds, did not fluctuate significantly and was not significantly affected by habitat types, although it was nearly significant in some species like Yellow-whiskered Greenbul and Olive Sunbird, showing an increasing pattern with increasing habitat modification. Overall wing asymmetry, as well as for the three most abundant species and for insectivorous birds, fluctuated significantly, but was not significantly affected by habitat types. Tail asymmetry for the three studied species, and to some extent for the overall

mist-netted community, did not significantly fluctuate and was not significantly affected by habitat types. The difference in tail asymmetry for insectivorous birds seemed to be significantly affected by habitat types, although no clear pattern could be defined. Across all species, the number of recaptures, as well as the recapture rate, were not significantly affected by habitat types, but near-primary forest showed the lowest numbers/proportions of recaptures. On species level, this pattern was also observed in Little Greenbul. But, the Yellow-whiskered Greenbul showed the opposite pattern with no recaptures in annual cultures; Olive Sunbird also indicated lowest recaptures in annual cultures. Individuals of insectivorous species showed a higher number of recaptures in natural habitats than in land use systems, although no clearly defined pattern could be observed using with the proportion of recaptures (see Chapter V.).

Key words: Cameroon, Central Africa, Forest conversion, Habitat quality for birds, Korup region, Land use systems.

VIII.1. Introduction

Anthropogenic disturbances to natural habitats create the need for methods to monitor the size and quality of wildlife populations (Anciães & Marini 2000). If secondary habitats are of a different habitat quality for birds than primary habitats, population structure will differ (e.g. proportion of adult territory owners), as well as various autecological variables. E.g. environmental stress can be determined using direct indices such as parasite loads, but also indirect measures such as fluctuating asymmetry or the occurrence of fault bars (Lens *et al.* 1999, Anciães & Marini 2000, Sodhi 2002). Fluctuating asymmetry was defined as the difference between the right and the left sides of characters that should otherwise be bilaterally symmetrical, but whose expression is affected by epigenetic stress during development (Anciães & Marini 2000). It is also a trait-specific susceptibility that has normally been attributed to different degrees of developmental stability, which could be caused by different modes of selection, functionality, or the stress experienced during the development process (Aparicio & Bonal 2002). Fault bars are translucent bands or more rarely spot in feathers, produced by stressful and adverse conditions during feather formation and caused by defective barbules formation, and they are often points of breakage (King & Murphy 1984, Stiefel 1985, Erritzoe in press).

Many studies have shown that forest clearance affects both habitat selection and movements of birds (Simberloff 1995, Wiens 1995), decreases food supplies and nest site availability (Rappole & Morton 1985, Burke & Nol 1998), and increases nest predation and parasitism (Robinson 1989). The habitat use of understorey birds in tropical forests is often measured in terms of capture rates or numbers of captured individuals (see Schemske & Brokaw 1981, Levey 1988, Lambert 1992). But the often drawn conclusion that higher capture rates are generally linked to higher habitat quality remains questionable. Incomplete understanding of bird behaviour and population dynamics in secondary habitats indicates that capture rates should be interpreted with great caution. In territorial species under high population pressure, capture rates can be much higher in sub-optimal habitats than in optimal habitats. In a complex habitat mosaic, even an inverse relationship between relative abundance and habitat quality may exist due to higher movement rates of sub-ordinate individuals (Winker *et al.* 1995). A more reliable indicator of habitat quality is therefore the number of sedentary individuals in a given area. In view of source-sink population theories (Pulliam *et al.* 1992, Dias 1996), low recapture rates of bird species can indicate differences in habitat quality between logged and unlogged forests, even when no apparent differences are found in relative abundances (see Dranzoa 1998).

This chapter aimed at assessing habitat factors that influence birds directly or indirectly such as indices of parasitism (from material collected from trapped birds), fluctuating asymmetry, occurrence of fault bars (Stiefel 1985), average body weight and proportion of territory owners/sedentary bird. We hypothesized that: (1) The level of parasitism, fluctuating asymmetry and fault bars should increase with increasing disturbance; (2) The average body weight of individuals should decrease with increasing disturbance (see Waltert 2000a); (3) Even if no significant difference was found in overall mist-net bird abundance between habitat types (§ Chapter V.), the proportion of adult territory owners (recaptured rates) should decrease with increasing habitat modification (read also Winker *et al.* 1995, Dranzoa 1998).

VIII.2. Methods

VIII.2.1. Data collection

Mist-netted birds (see detail method for trapping birds in §V.2.1.) were identified and sides of their two tarsi were painted referring to each study site, with a waterproof bold marker, to be able to distinguish recaptured individuals from one site from those of different study sites.

The amount of skull pneumatization was determined to separate adult passerines (after the first year) from juveniles (Ralph *et al.* 1993). All bird individuals captured were closely examined for plumage and skin parasites (i.e. ectoparasites, e.g. chewing lice, mite, tick, order Mallophaga). The birds were weighted; biometrical measurements of commonly used morphological features (body, wing, tail and tarsus length) were also taken for both body sides. Apart from these commonly used biometrical data, the number of fault bars was counted by examining tail feathers against sunlight (Stiefel 1985). All measurements were taken by two observers and mean values were calculated for both body sides in order to minimize sampling errors due to recorder variability. Birds found at 18h00 in mist-nets were kept in cotton bags until 7h00 the next day to avoid possible disorientation of animals when released in the dark.

VIII.2.2. Data analysis

Data were first sorted to separate recaptured individuals from the whole mist-netting data set. For each sampling station, the number of recaptured individuals i.e. the number of adult territory owners was calculated; the proportion of recaptures to the number of individuals captured was also calculated. This was also done for each of the three most abundant species in our mist-net community. This was also done specifically for the group of insectivores, which presented contrasting results in chapter V, i.e. a decreasing pattern of captures, and an increasing pattern of individuals, with increasing habitat modification; thus we could logically expect a higher number of adult territory owners of insectivorous in natural habitats than in land use systems (to be checked).

Overall average body weight was calculated in each plot for each sex. A *t* test was then done to detect if average weight differed between sexes, to be able to treat them separately. Average body weight was also calculated for each of the three most abundant species mist-netted namely Little Greenbul, Yellow-whiskered Greenbul and Olive Sunbird.

Fluctuating asymmetry was evaluated using the overall tarsi, the wings (max) and tail (R) sides lengths, as well as for the three most abundant species mist-netted; the average lengths of each side were calculated and a *t* test was used to compare averages of both sides; in case of significant difference between both sides, the difference in average lengths was also deduced. Non-parametric analysis of variance (Kruskal –Wallis ANOVA) was used to determine if these parameters differed between habitats.

The number of bird individuals and species carrying ectoparasites, as well as the proportion of infested individuals and species to the number of individuals and species checked were also calculated. Gamma-rank correlation coefficient was also computed in order to determine the relationships between this parameter and overall understorey bird species richness and abundance.

The number of bird individuals and species presenting fault bars on wings, as well as their proportion to the number of individuals checked were also calculated.

One way ANOVA was used to detect significant difference between habitat types for each of the studied parameters. Means are given with standard deviation if not mentioned otherwise. Tukey's Honest Significance Difference-Test (HSD test) was used for multiple comparisons of means.

One-way ANOVA, Kruskal –Wallis ANOVA and all other statistical analyses were performed using STATISTICA 6.0 (StatSoft 2001).

VIII.3. Results

VIII.3.1. Average body weight

The average body weight of individuals across species did not differ between sexes ($t = 1.60$, $df = 23$, $P = 0.12$). Overall average body weight (male and female mixed) was significantly affected by habitat types (One-way ANOVA, Overall: $F_{3,20} = 3.86$, $P = 0.025$). A clear decreasing pattern was found from near-primary forest to annual cropland: Highest overall average body weight was found in NF (25.8 ± 3.4); it was slightly lower in SF (23.7 ± 2.7) and CF (20.9 ± 4.9), and was significantly lower in AC (19.2 ± 3.2) (see Fig. VIII.1., see also Table VIII.1.).

Average body weights of Little Greenbul and Yellow-whiskered Greenbul were not significantly affected by habitat modification (One-way ANOVA, for Little Greenbul: $F_{3,16} = 0.99$, $P = 0.42$; for Yellow-whiskered Greenbul: $F_{3,19} = 2.11$, $P = 0.13$), and no clear defined patterns were found. But, average body weight of Olive Sunbird was significantly affected by habitat types (One-way ANOVA, for Olive Sunbird: $F_{3,20} = 9.07$, $P = 0.0005$) and NF showed the highest average body weight as compared to other habitat types (see Table VIII.1.).

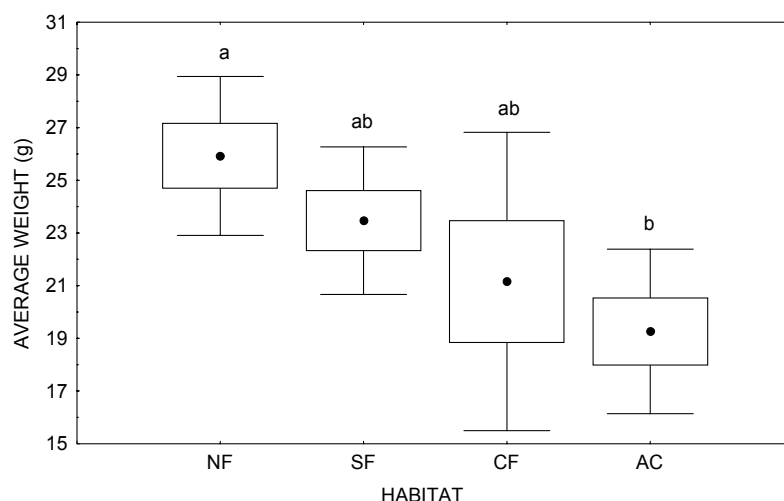


Figure VIII.1.: Average body weight (g) for overall species mist-netted. The points indicate the mean values; Error bars indicate (mean \pm standard deviation) and the boxes indicate (mean \pm standard error); Different letters indicate significant differences between habitat types (Tukey 's Honest Significant Difference-Test). Habitat types are NF for near-primary forest, SF for secondary forest, CF for agroforestry systems and AC for annual cultures.

Table VIII.1.: Average body weight (g) of overall mist-net community, as well as for the three most abundant species found. Mean values are given (\pm standard deviation). Results of One-way ANOVA are also presented.

	Habitat				$F_{3,20}$	P
	NF	SF	CF	AC		
Overall*	25.8(3.4)	23.7(6.7)	20.9(4.9)	19.2(3.2)	3.86	0.025
Little Greenbul	22.5(2.1)	23.9(5.4)	20.7(1.7)	22.6(0.6)	0.99	0.42
Yellow-whiskered Greenbul	26.2(1.6)	27.4(1.4)	26.3(1.3)	28.4(2.3)	2.11	0.13
Olive Sunbird***	10.3(1.1)	9.1(0.4)	8.1(0.8)	9.8(0.7)	9.07	0.0005

Notes: Significant difference * for $p < 0.05$ and *** for $p < 0.001$. See Fig. VIII.1. for abbreviations of habitat types.

VIII.3.2. Parasite loads

The number individuals infested with ectoparasites, as well as their proportion, per sampling station, was not significantly affected by habitat types (One-way ANOVA, for number of

infested individuals: $F_{3,20} = 2.06$, $P = 1.14$; Kruskal-Wallis ANOVA, for proportion of infested individuals: $H_{3,24} = 6.37$, $P = 0.095$). Nonetheless, natural habitats (NF and SF) showed highest bird individuals and proportion infested by ectoparasites than land use habitats (CF and AC), with a mean individuals of $9.0 (\pm 5.0)$ in NF, followed by SF (8.3 ± 5.0), AC (8.3 ± 4.1) and CF (3.8 ± 1.8) (see Fig. VIII.2A.); the mean percentage of infested individuals was highest in NF (21.2 ± 10.0), followed by AC (16.9 ± 9.6) and SF (16.3 ± 7.9), then by CF (8.9 ± 2.9) (see Fig. VIII.2B.).

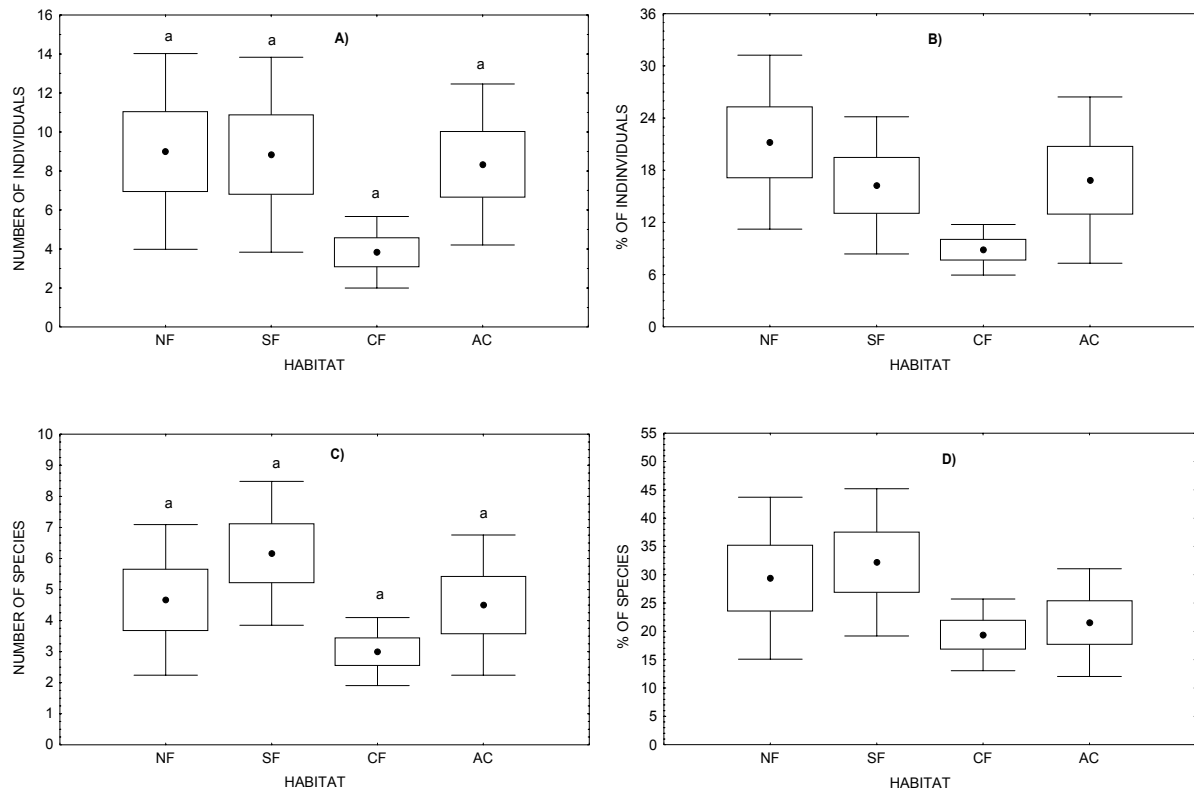


Figure VIII.2.: A) Number of infested individuals, B) Percentage of infested individuals, C) Number of infested species and D) Percentage of infested species; The points indicate the mean values; Error bars indicate (mean \pm standard deviation) and the boxes indicate (mean \pm standard error); a in all cases indicates no significant differences (Tukey 's Honest Significant Difference-Test). See Fig. VIII.1. for abbreviations of habitat types.

The number of species infested with ectoparasites, as well as their proportion, per sampling station, was also not significantly affected by habitat types (One-way ANOVA, for number of infested species: $F_{3,20} = 2.29$, $P = 0.11$; Kruskal-Wallis ANOVA, for proportion of infested

species: $H_{3,24} = 4.55$, $P = 0.21$). Nonetheless, natural habitats (NF and SF) also showed highest number of species and proportion infested by ectoparasites than land use habitats (CF and AC), with a mean individuals of $6.2 (\pm 2.3)$ in SF, followed by NF (4.7 ± 2.4) and AC (4.5 ± 2.3), then by CF (3.0 ± 1.1) (see Fig. VIII.2C., Table VIII.2.); The mean percentage of infested species was highest in SF (32.2 ± 13.0), followed by NF (29.4 ± 14.2), AC (21.5 ± 9.5) and CF (19.4 ± 5.3) (see Fig. VIII.2D., Table VIII.2.).

Table VIII.2.: Species infested with ectoparasites in different habitat types.

Species	Habitat			
	NF	SF	CF	AC
Woodland Kingfisher				+
White-bellied kingfisher		+		
Yellowbill				+
Speckled Thinkerbird			+	+
Yellow-spotted Barbet		+		
Long-billed Pipit				+
Little Greenbul			+	+
Icterine Greenbul	+			
Red-tailed Greenbul		+		
Yellow-whiskered Greenbul	+	+	+	+
Sjöstedt's Honeyguide Greenbul		+		
Lesser Bristlebill	+	+	+	+
Red-tailed Bristlebill	+			
White-tailed Ant-Thrush		+	+	
Fire-crested Alethe	+	+	+	+
Brown-chested Alethe	+	+		
Forest Robin	+	+	+	
Brown Illadopsis		+		
Black-capped Illadopsis	+	+		
Pale-breasted Illadopsis	+	+		
Grey-ground Thrush		+		
Green Hylia		+		+
Grey-backed Camaroptera				+
Olive green Camaroptera				+
Blue-headed crested Flycatcher	+	+	+	
Red-bellied paradise Flycatcher	+			
Rufous-vented Paradise Flycatcher		+		
White-browed Forest Flycatcher		+		
Vieillot's black Weaver				+
Grey-crowned Negrofinch				+
Chestnut-breasted Negrofinch				+

Yellow-bellied Wattle-eye	+			
Red-checked Wattle-eye			+	
Western Bluebill	+			+
Total	13	18	9	15

Notes: + confirms the infestation; in bold are species infested in all habitat types; See Fig. VIII.1. for abbreviations of habitat types.

All relationships between the studied parameters concerning infested birds and overall understorey bird species richness and abundance were very weak and insignificant (see Table VIII.3).

Table VIII.3.: Gamma-rank correlation coefficient between parameters on infested birds and overall understorey bird species richness and abundance (read Chapter V.)

Parameters	γ	<i>P</i>
Infested individuals & Overall abundance	0.173	0.262
Infested individuals & Overall observed species richness	0.033	0.831
% of infested individuals & Overall individuals	-0.154	0.294
% of infested individuals & Overall observed species richness	-0.241	0.108
Number of infested species & Overall individuals	0.198	0.203
Number of infested species & Overall observed species richness	0.123	0.432
% of infested species & Overall individuals	-0.027	0.859
% of infested species & Overall observed species richness	-0.146	0.337

Notes: N = 24 in all cases;

VIII.3.3. Fault bars

The number individuals presenting fault bars, as well as their proportion, per sampling station, was significantly affected by habitat types (One-way ANOVA, for number of individuals with fault bars: $F_{3,20} = 14.94$, $P < 0.001$; Kruskal-Wallis ANOVA, for proportion of individuals with fault bars: $H_{3,24} = 16.48$, $P = 0.0009$). A clear increasing pattern was observed from near-primary forest to farmland: AC showed highest number of individuals with fault bars with a mean value of $6.3 (\pm 2.4)$; it was slightly lower in CF (4.0 ± 1.3), and was significantly lower in SF (3.7 ± 0.5) and NF (0.5 ± 1.2) (see Fig. VIII.3A.); the mean percentage of individuals

with fault bars was still highest in AC (12.7 ± 4.8), lower respectively in CF (9.7 ± 4.0) and SF (7.3 ± 1.3), and lowest NF (1.0 ± 2.4) (see Fig. VIII.3B.).

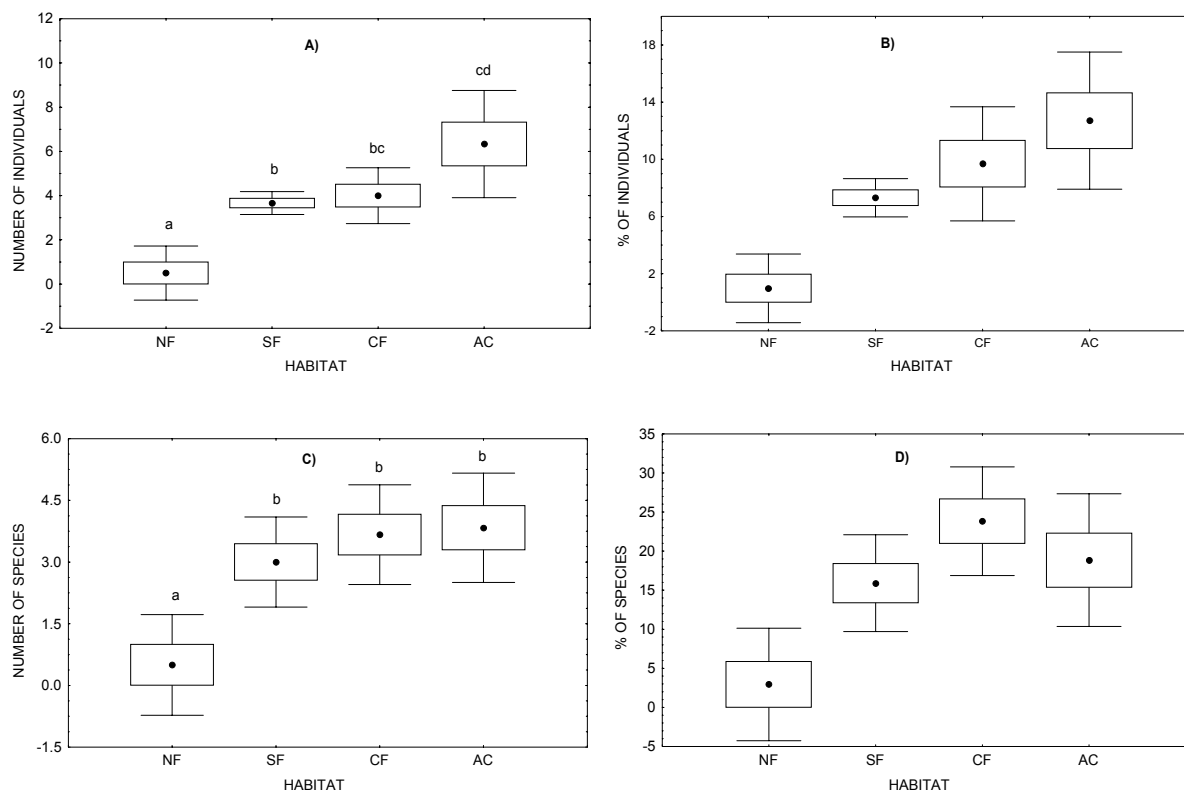


Figure VIII.3.: A) Number of infested individuals, B) Percentage of infested individuals, C) Number of infested species and D) Percentage of infested species; The points indicate the mean values; Error bars indicate (mean \pm standard deviation) and the boxes indicate (mean \pm standard error); Different letters indicate significant differences (Tukey 's Honest Significant Difference-Test). See Fig. VIII.1. for abbreviations of habitat types.

The number of species presenting fault bars, as well as their proportion, per sampling station, was also significantly affected by habitat types (One-way ANOVA, for number of species with fault bars: $F_{3,20} = 9.63$, $P < 0.001$; Kruskal-Wallis ANOVA, for proportion of species with fault bars: $H_{3,24} = 11.50$, $P < 0.01$). A clear increasing pattern was found from near-primary forest to farmland. AC showed highest number of species with fault bars with a mean value of $3.8 (\pm 1.3)$; it was slightly lower in CF (3.7 ± 1.2) and SF (3.0 ± 1.1), and significantly lower in NF (0.5 ± 1.2) (see Fig. VIII.3C., Table VIII.4.). The mean percentage

of species with fault bars was highest in CF (23.8 ± 7.0), lower respectively in AC (18.9 ± 8.5), SF (15.9 ± 6.2), and lowest in NF (2.9 ± 7.2) (see Fig. VIII.3D., Table VIII.4.).

Table VIII.4.: Species presenting fault bars in different habitat types.

Species	Habitat			
	NF	SF	CF	AC
White-bellied kingfisher	+			
Black Bee-eater		+		
Speckled Thinkerbird			+	+
Yellow-spotted Barbet		+		
Long-billed Pipit				+
Least Honeyguide			+	
Spotted Honeyguide			+	
Baumann's Greenbul				+
Little grey Greenbul			+	
Little Greenbul			+	+
Eastern-bearded Greenbul		+		
Yellow-whiskered Greenbul	+	+	+	
White-tailed Ant-Thrush		+	+	
Forest Robin		+	+	
Fire-crested Alethe		+	+	
Brown-chested Alethe		+		
Blue-headed crested Flycatcher		+	+	
Red-bellied paradise Flycatcher		+	+	
Rufous-vented Paradise Flycatcher			+	
Green Hylia			+	
Grey-backed Camaroptera				+
Olive Sunbird		+	+	+
Olive-bellied Sunbird				+
Johanna's Sunbird		+		
Black-necked Weaver				+
Chestnut Wattle-eye		+		
Green Twinspot				+
Chestnut-breasted Negrofinch				+
Western Bluebill	+	+	+	+
Total	3	14	15	11

Notes: + confirms the presence of fault bars in respective species; in bold is the species with fault bars in all habitat types. See Fig. VIII.1. for abbreviations of habitat types.

VIII.3.4. Fluctuating asymmetry

VIII.3.4.1. Tarsus

The tarsus average lengths of the overall mist-netted community did not differ between both sides ($t = 1.15$, $df = 23$, $P = 0.26$). Overall average length difference between both tarsi was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,24} = 1.20$, $P = 0.75$). But, NF seemed to show the greatest difference in average lengths between both tarsi as compared to other habitat types (see Fig. VIII.4A.).

The tarsus average lengths of Little Greenbul did not also differ between both sides ($t = 1.40$, $df = 19$, $P = 0.18$). Its average length difference between both tarsi was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,20} = 1.37$, $P = 0.71$). But, NF seemed to show the greatest difference in average lengths between both tarsi as compared to other habitat types (see Fig. VIII.4B.).

The tarsus average lengths of Yellow-whiskered Greenbul were just nearly significantly different between both sides ($t = 1.99$, $df = 21$, $P = 0.06$). Its average length difference between both tarsi was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,22} = 5.24$, $P = 0.15$). Nonetheless, a clear increasing pattern can be observed from near-primary forest to annual cropland (see Fig. VIII.4C.).

The tarsus average lengths of Olive Sunbird did not also differ between both sides ($t = 1.48$, $df = 23$, $P = 0.15$). Its average length difference between both tarsi was nearly significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,22} = 7.25$, $P = 0.064$). Nonetheless, a clear increasing pattern can be observed from near-primary forest to land use systems (see Fig. VIII.4D.).

The tarsus average lengths of Insectivores did not also differ between both sides ($t = 1.17$, $df = 23$, $P = 0.25$). Its average length difference between both tarsi was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,24} = 1.68$, $P = 0.642$). Nonetheless, near-primary forest showed a higher tarsus fluctuating asymmetry as compared to other habitat types (see Fig. VIII.4E.).

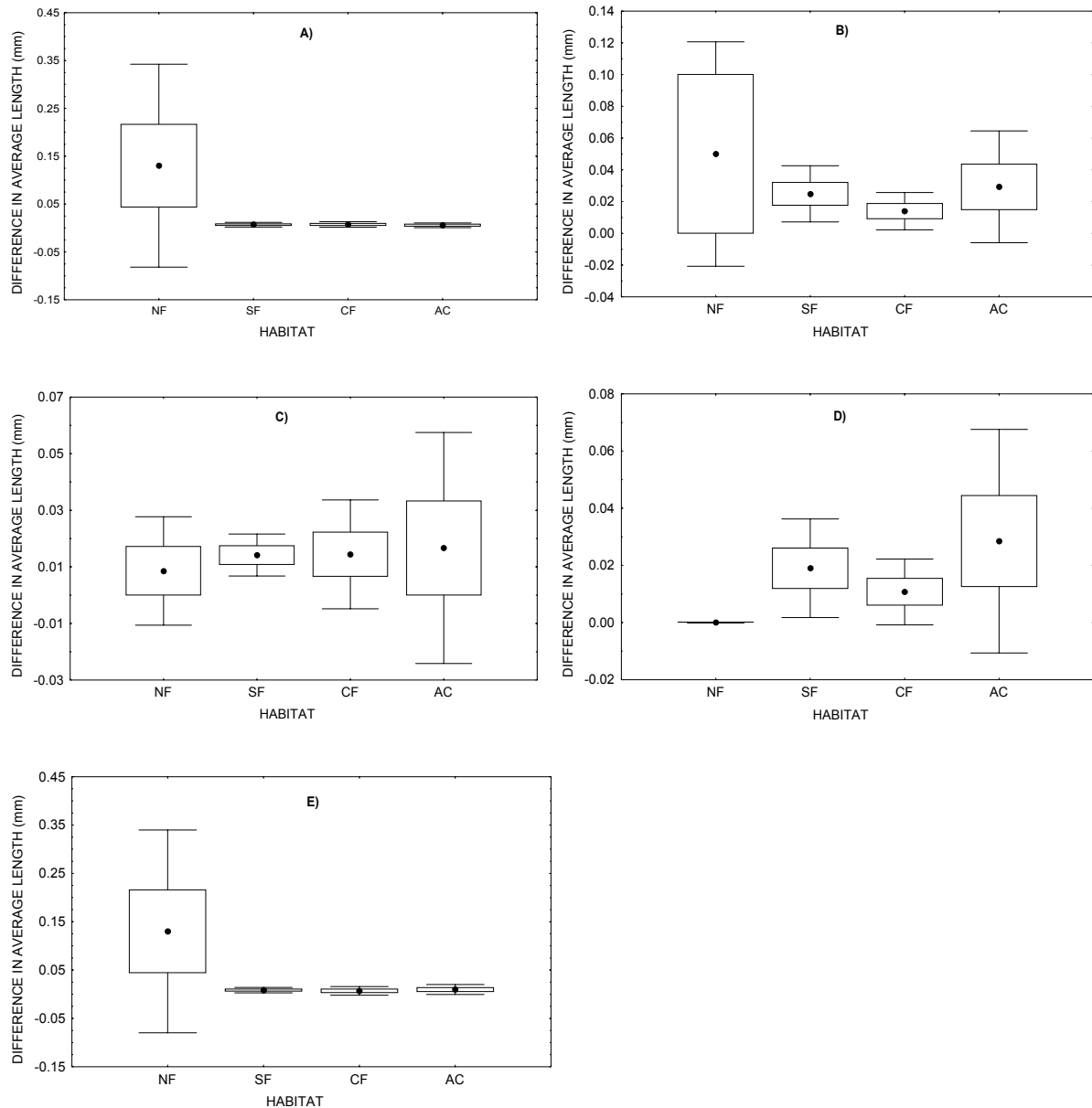


Figure VIII.4.: Differences in average length (mm) between both tarsi for A): Overall mist-netted community, B) Little Greenbul, C) Yellow-whiskered Greenbul, D) Olive Sunbird and E) Insectivores; The points indicate the mean values; Error bars indicate (mean \pm standard deviation) and the boxes indicate (mean \pm standard error). See Fig. VIII.1. for abbreviations of habitat types.

VIII.3.4.2. *Wing (max)*

The wing average lengths of the overall mist-netted community showed significant difference between both sides ($t = 7.32$, $df = 23$, $P < 0.001$). Overall average length difference between both wings was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall:

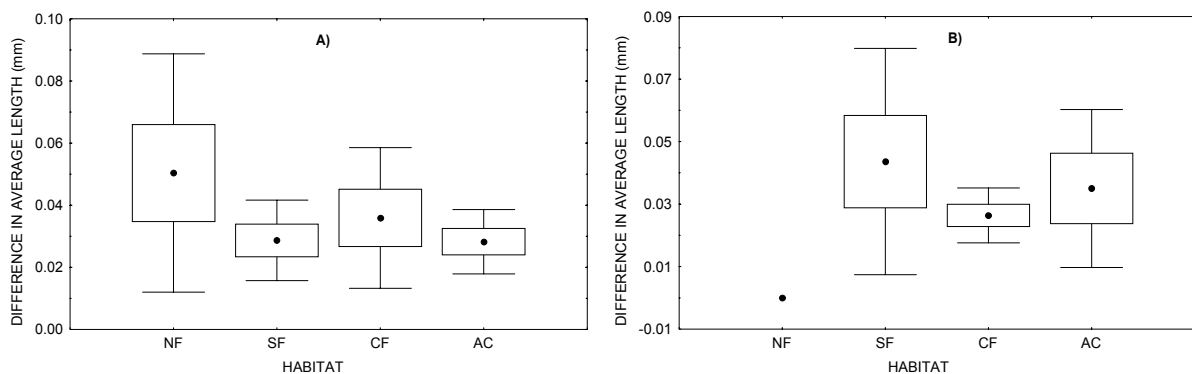
$H_{3,24} = 1.19$, $P = 0.76$). But, NF seemed to show the greatest difference in average lengths between both wings as compared to other habitat types (see Fig. VIII.5A.).

The wing average lengths of Little Greenbul also differed significantly between both sides ($t = 3.76$, $df = 17$, $P = 0.0016$). Its average length difference between both wings was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,18} = 2.61$, $P = 0.46$). No clearly defined pattern was found between different habitat types, but NF seemed to show the lowest difference (see Fig. VIII.5B.).

The wing average lengths of Yellow-whiskered Greenbul were also significantly different between both sides ($t = 3.25$, $df = 16$, $P = 0.005$). Its average length difference between both wings was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,17} = 1.74$, $P = 0.63$). No clearly defined pattern was found between different habitat types, but NF seemed to show the lowest difference (see Fig. VIII.5C.).

The wing average lengths of Olive Sunbird were also difference between both sides ($t = 4.42$, $df = 21$, $P < 0.001$). Its average length difference between both wings was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,22} = 4.55$, $P = 0.1$). No clearly defined pattern was found between different habitat types (see Fig. VIII.5D.).

The wing average lengths of Insectivores were also difference between both sides ($t = 2.36$, $df = 23$, $P = 0.027$). Its average length difference between both wings was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,24} = 2.37$, $P = 0.5$). No clearly defined pattern was found between different habitat types (see Fig. VIII.5E.).



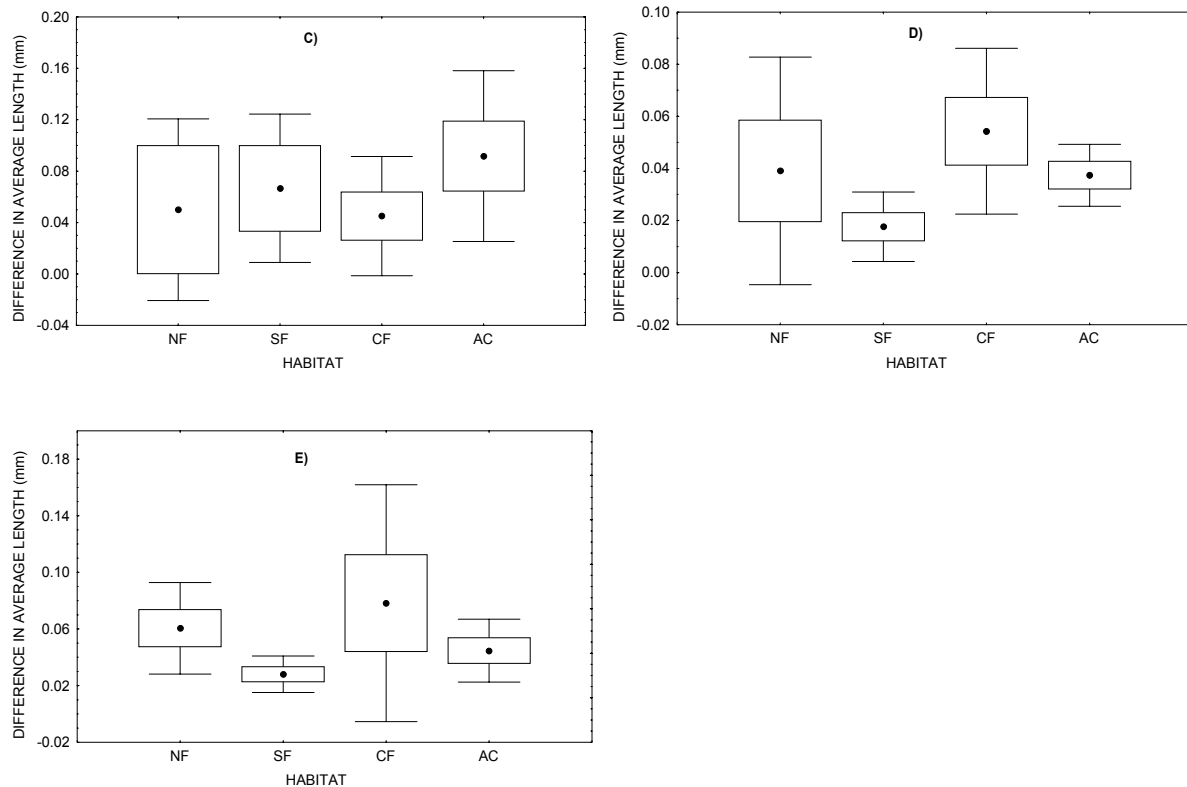


Figure VIII.5.: Differences in average length (mm) between both wings for A) Overall mist-netted community, B) Little Greenbul, C) Yellow-whiskered Greenbul, D) Olive Sunbird and E) Insectivores; The points indicate the mean values; Error bars indicate (mean \pm standard deviation) and the boxes indicate (mean \pm standard error). See Fig. VIII.1. for abbreviations of habitat types.

VIII.3.4.3. Tail (R)

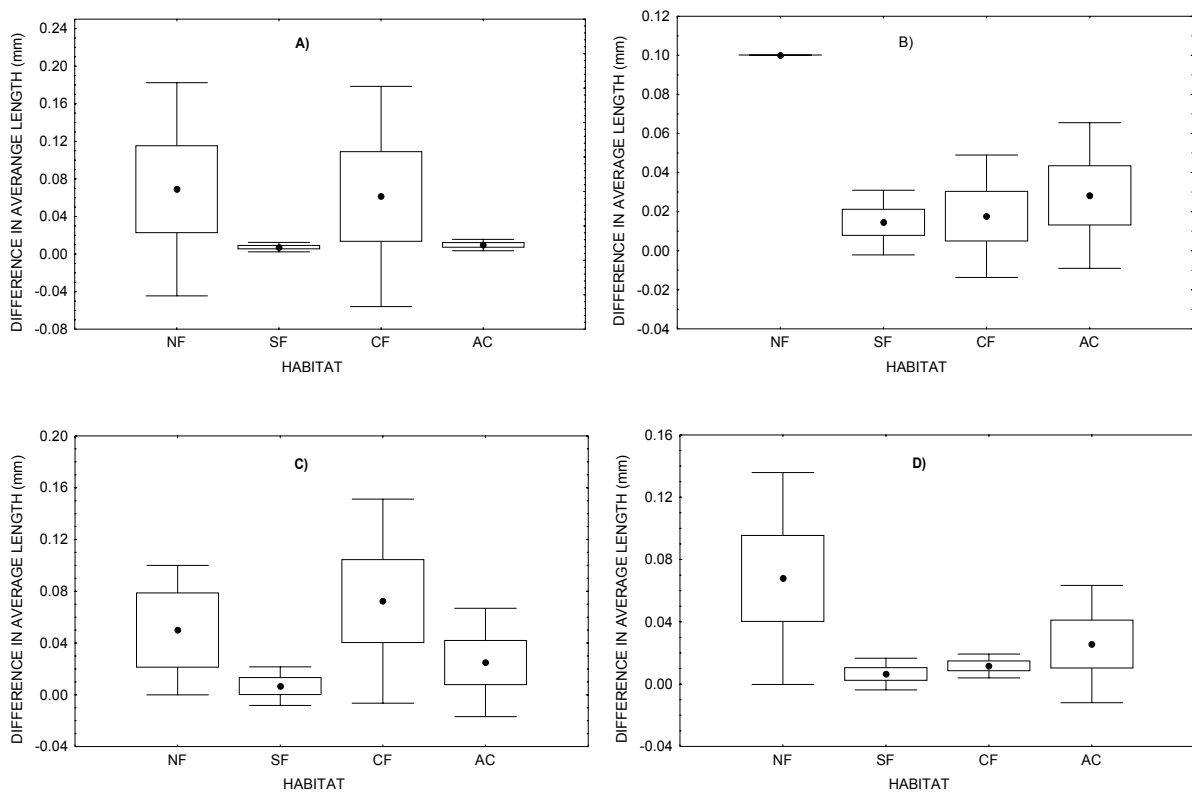
The tail side average lengths of the overall mist-netted community showed almost significant difference between both sides ($t = 1.98$, $df = 23$, $P = 0.059$). Overall average tail lengths difference was significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,24} = 9.69$, $P = 0.021$). No clearly defined pattern was observed in overall average tail lengths difference from near-primary forest to annual croplands (see Fig. VIII.6A.).

The tail side average lengths of Little Greenbul did not differ significantly between both sides ($t = 1.41$, $df = 19$, $P = 0.174$). Its average length difference between both tail sides was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,20} = 5.46$, $P = 0.141$). No clearly defined pattern was found between different habitat types, but NF seemed to show the lowest difference (see Fig. VIII.6B.).

The tail side average lengths of Yellow-whiskered Greenbul were not significantly different between both sides ($t = 1.38$, $df = 19$, $P = 0.185$). Its average length difference between both tail sides was not significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,20} = 6.42$, $P = 0.093$). No clearly defined pattern in average tail lengths difference of Yellow-whiskered Greenbul was found between different habitat types (see Fig. VIII.6C.).

The tail side average lengths of Olive Sunbird were not difference between both sides ($t = 0.69$, $df = 23$, $P = 0.497$). Its average length difference between both tail sides was nearly significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,24} = 7.08$, $P = 0.069$). No clearly defined pattern in average tail lengths difference of Olive Sunbird was found between different habitat types, but NF seemed show the highest difference (see Fig. VIII.6D.).

The tail side average lengths of Insectivores were not difference between both sides ($t = 1.63$, $df = 23$, $P = 0.117$). Its average length difference between both tail sides was significantly affected by habitat types (Kruskal–Wallis ANOVA, Overall: $H_{3,24} = 8.30$, $P = 0.040$). No clearly defined pattern in average tail lengths difference of Insectivores was found between different habitat types, but CF seemed show the highest difference (see Fig. VIII.6E.).



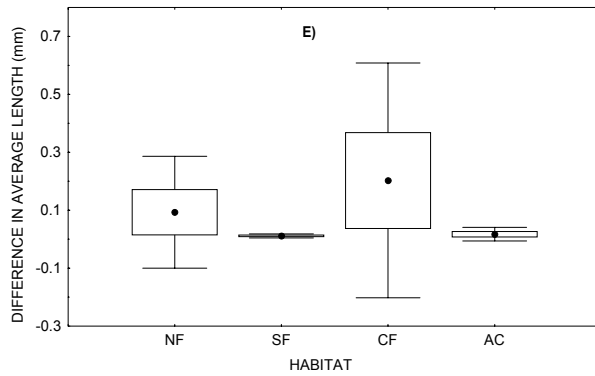


Figure VIII.6.: Differences in average length (mm) between both tail sides for A): Overall mist-netted community, B) Little Greenbul, C) Yellow-whiskered Greenbul, D) Olive Sunbird and E) Insectivores; The points indicate the mean values; Error bars indicate (mean \pm standard deviation) and the boxes indicate (mean \pm standard error). See Fig. VIII.1. for abbreviations of habitat types.

VIII.3.5. Adult territory owners

The number of recaptured individuals i.e. the number of adult territory owners per sampling station, as well as the proportion of recaptures was not significantly affected by habitat types (One-way ANOVA, for recaptured individuals: $F_{3,20} = 2.22$, $P = 0.12$; Kruskal–Wallis ANOVA, for recaptures proportion: $H_{3,24} = 3.38$, $P = 0.34$). No clearly defined patterns were observed: NF showed the lowest record with a mean recaptured individuals of $6.0 (\pm 3.4)$, followed by AC (8.8 ± 4.1), CF (10.5 ± 4.8) and SF (11.3 ± 3.0) (see Fig. VIII.7A., Table VIII.5.). A similar trend was observed with the proportion of recaptures where NF showed the lowest average percentage of adult territory owners of $12.9 (\pm 6.7)$, followed by AC (17.6 ± 9.7), CF (18.9 ± 5.0) and SF (19.7 ± 5.6) see Fig. VIII.7B., Table VIII.5.).

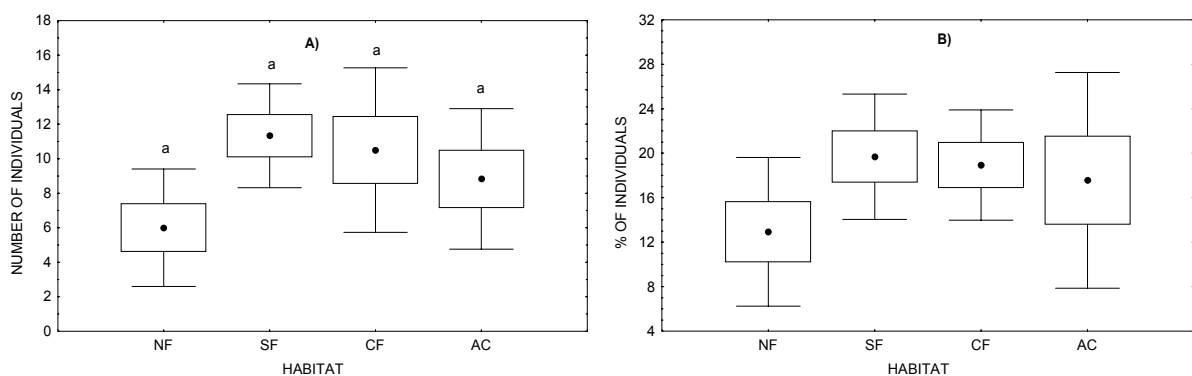


Figure VIII.7.: A): Number of recaptured individuals, B) Percentage of recaptured individuals; The points indicate the mean values; Error bars indicate (mean \pm standard

deviation) and the boxes indicate (mean \pm standard error); a in all cases indicates no significant differences (Tukey 's Honest Significant Difference-Test).

For the three most abundant species of our mist-net community, recaptured individuals of Little Greenbul, as well as its recaptured proportion, showed significant difference between habitat types (One-way ANOVA, for recaptured individuals: $F_{3,20} = 4.94$, $P < 0.01$; Kruskal–Wallis ANOVA, for recaptures proportion: $H_{3,24} = 13.57$, $P < 0.01$). In both cases, NF and SF showed lowest records (see Table VIII.5.).

In both cases, Olive Sunbird did not showed significant difference between habitat types (One-way ANOVA, for recaptured individuals: $F_{3,20} = 2.09$, $P = 0.13$; Kruskal–Wallis ANOVA, for recaptures proportion: $H_{3,24} = 4.63$, $P = 0.20$), and no clearly defined patterns were found (see Table VIII.5.).

Yellow-whiskered Greenbul recaptured individuals, as well as the proportion of recaptures, were significantly affected by habitat types (One-way ANOVA, for recaptured individuals: $F_{3,20} = 6.67$, $P < 0.01$; Kruskal–Wallis ANOVA, for recaptures proportion: $H_{3,24} = 12.42$, $P < 0.01$); still, NF had almost the lowest records (see Table VIII.5.).

While recaptured individuals of insectivores were significantly affected by habitat types (One-way ANOVA, $F_{3,20} = 4.19$, $P = 0.019$), their proportions were not (Kruskal–Wallis ANOVA, $H_{3,20} = 4.90$, $P = 0.179$). As predicted, natural habitats showed higher number of recaptured individuals than land use systems, although the pattern for their proportions was not clearly defined (see table VIII.5.).

Table VIII.5.: Number and percentage of recaptured individuals for overall mist-net community, as well as for the three most abundant species found and for the group of insectivores. Mean values are given (\pm standard deviation). Results of one-way ANOVA and Kruskal Wallis ANOVA are also presented.

		Habitat				$F_{3,20}$	
		NF	SF	CF	AC	$H_{3,24}$	P
Overall	Number of individuals	4.8(2.3)	8.5(2.3)	8.2(5.7)	6.8(4.2)	1.09	0.38
	% individuals	11.4(5.5)	15.5(4.1)	14.8(7.4)	12.8(6.9)	3.38	0.34
Insectivores	Number of individuals*	4.7(2.8)	7.8(2.5)	2.5(2.1)	4.2(3.2)	4.19	0.019
	% individuals	12.5(7.5)	23.3(9.1)	12.7(7.3)	20.3(14.4)	4.90	0.179
Little Greenbul	Number of individuals**	0.0(0.0)	0.0(0.0)	1.3(1.5)	1.7(1.2)	4.94	0.0099
	% individuals**	0.0(0.0)	0.0(0.0)	8.6(9.0)	14.9(10.6)	13.57	0.0036
Yellow-whiskered Greenbul	Number of individuals**	0.3(0.8)	1.5(0.6)	0.8(0.7)	0.0(0.0)	6.67	0.0027
	% individuals**	6.6(16.3)	29.3(35.0)	14.6(18.8)	0.0(0.0)	12.42	0.0061
Olive Sunbird	Number of individuals	0.8(1.6)	1.8(2.1)	3.8(4.4)	0.3(0.8)	2.09	0.13
	% individuals	9.4(16.4)	21.2(18.2)	18.6(21.0)	4.2(10.2)	4.63	0.20

Notes: Significant difference * for $p < 0.05$ and ** for $p < 0.01$.

VIII.4. Discussions

VIII.4.1. Body weight

As predicted, body weight across species was significantly affected by habitat types and it decreased with increasing habitat modification. This could mean that natural habitats are of better quality for birds as compared to land use systems. Similar results were obtained in Sierra Yalijux, Alta Verapaz, Guatemala, where body mass in understorey bird community was higher in natural forest than in young secondary forest, and was attributed to better nutrition resources in the first habitat type (Renner 2003). In our study case, the food resources present in natural habitats, although fewer in abundance (see Chapter VII.), are shared by a lower number of individuals observed (see Chapter V.) and consequently, their body mass is higher, as compared to modified habitats. Differently, habitat degradation did not negatively affect body condition in Linggoasri, Central Java (Sodhi *et al.* 2005). We could thus expect a linear negative relationship between body mass and abundance of birds in our study area. But this type of negative relationship is more apparent in species with larger range

of body sizes/mass like in mammals and flightless birds (read e.g. Damuth 1981, Ebenman *et al.* 1995). In our study case, we found an almost null and insignificant correlation between body mass and abundance in birds (Spearman-rank correlation coefficient, $r_s = 0.063$, $P = 0.77$). Similarly, many studies reported little or no relationship, or a triangle relationship between body size and abundance in many taxa (flying birds, moths, ...) as a result of their narrower range of body sizes (e.g. Brown & Maurer 1986, Gaston 1988).

VIII.4.2. Parasite loads

Contrary to our hypotheses, we found that near primary forest had the highest number and proportion of infested individuals and species as compared to other habitat types. Thus, it seemed like land use systems in our study area are of a much better quality for understorey birds than natural habitats as far as parasite loads is concerned. Similarly, lower rates of ectoparasitism in *Norops polylepis* (a lizard) were found along edges than in forest fragment interiors in Las Cruces, Costa Rica, and were attributed to specific biological requirements of each taxon (Schlaepfer & Gavin 2001). Other study reported no difference in ectoparasites prevalence and intensity between forest fragments and continuous forests in Singapore (Sodhi 2002). Similarly, no significant difference was found in the proportion of individuals with ectoparasites between selectively logged and secondary forests in Linggoasri, Central Java (Sodhi *et al.* 2005). But, Robinson's study (1989) indicated an increase of parasitism when the forests are degraded. On the same line, primary forest in the Danum Valley, Sabah, in Malaysia had been reported to have significantly less ectoparasites in small mammals (particularly rats) than secondary forest (Mckay 2006).

VIII.4.3. Fault bars

As predicted, the fault bars parameters gradually increased with increasing habitat modification. Both the number and proportion of individuals, and species, presenting fault bars on wings, were significantly lower in near-primary forest compared to other habitat types. The situation was similar in Singapore where more individuals had fault bars in forest fragments compared to those in continuous forests (Sodhi 2002). But in Linggoasri, Central Java, the proportion of individuals with fault bars was not significantly different between selectively logged and secondary forests (Sodhi *et al.* 2005). Forest modification could affect birds in our study area as far as the occurrence of fault bars is concerned. It could have been

caused by stressful conditions other than the food scarcity as the food was found to be more available in land use systems than in natural habitats (see Chapter VII.). Similarly, no correlation was found between the incidence of fault bars and the food deprivation in pheasants (Solomon & Linder 1978). But, this essential resource was shared among more individuals in our study case (see Chapter V.) and at the end, the food for each individual in land use systems might be reduced as compared to the situation in natural habitats, thus creating a stressful condition which results in fault bars appearance. It could also be due to the habitat structure as it was experimentally proved that birds from aviaries with cover had fewer fault bars on primary feathers than birds from aviaries without cover (Witter & Lee 1995).

VIII.4.4. Fluctuating asymmetry

Overall tarsus asymmetry, as well as for the three most abundant species and for insectivorous birds, did not significantly fluctuate and was not significantly affected by habitat types, although some species like Yellow-whiskered Greenbul and Olive Sunbird seemed to show an increasing pattern with increasing habitat modification. Overall wing asymmetry, as well as for the three most abundant species and for insectivorous birds, fluctuated significantly, but was not significantly affected by habitat types. Tail asymmetry for the three studied species, and to some extent for the overall mist-netted community, did not significantly fluctuate and was not significantly affected by habitat types. The tail asymmetry for insectivorous birds was insignificantly different and seemed to be significantly affected by habitat types, although no clear pattern could be defined. Different results were obtained with overall passerine birds of Brazilian tropical forests where wing and tarsus fluctuating asymmetry were significantly greater in fragments than in continuous areas, and where differences in fluctuating asymmetry were more evident for insectivorous species, especially those feeding in or near the understorey (Anciães & Marini 2000). It was experimentally demonstrated that the habitat structure matters as birds from aviaries with cover had lower levels of fluctuating asymmetry than those from aviaries without cover (Witter & Lee 1995).

Thus, depending on traits and species, fluctuating asymmetry in understorey birds in our study area is different and it is not clear whether the fluctuating asymmetry observed is due to our gradient of disturbance. More evidence could be observed on wings, than on tarsi or tail. This might be explained by the fact that the expression of fluctuating not only depends on developmental stability (read Zakharov & Graham 1992), but also on the cost of growth of the trait, defined as the amount of structural components necessary to form a unit of length of a

given character (Aparicio & Bonal 2002). Thus, there are certain characters that are more susceptible to increase fluctuating asymmetry than others (Møller & Swaddle 1997, Clake 1998, Aparicio & Bonal 2002).

VIII.4.5. Recapture rates

Contrary to our hypotheses, we found that near-primary forest had the lowest recapture rates compared to other habitat types. Thus, it seems like land use systems in our study area is of a much better quality for understorey birds than natural habitats as far as adult territory owners are concerned. Opposite results were obtained in other studies (e.g. Pulliam *et al.* 1992, Winker *et al.* 1995, Dias 1996, Dranzoa 1998, Renner 2003), probably indicating that there are more possible territories in natural forests compared to secondary forests (Renner 2003). But, no significant difference was found in recapture rates between selectively logged and secondary forests in Linggoasri, Central Java (Sodhi *et al.* 2005). We suspected that territories in our land use systems are much smaller in size than those in natural habitats, probably as a result of a high competition for food that attracts many forest birds outside their normal territory. Evidence was found with insectivores that showed higher number of recaptured individuals in natural habitats than in modified habitats.

VIII.5. Conclusion

Considering parameters like body weight and fault bars, natural habitats could be of good quality for understorey birds compared to land use systems. Land use systems could also be of a much better quality for understorey birds than natural habitats as far as parasites load and adult territory owners are concerned, and it was evident that territories in land use systems are much smaller in size than those in natural habitats, meaning that there might be great migration and exchange fluxes between natural and land use habitats and many forest birds trapped in land use systems might have been temporally outside their nearby normal territory maybe searching for food that was assessed to be more abundant in degraded habitats (§ Chapter VII); this was particularly evident, as predicted (see chapter V.), for insectivores that showed a higher number of adult territory owners in natural habitats than in land use systems. Fluctuating asymmetry depends on traits and feeding guilds/groups, and there is no evidence that the observed patterns particularly on wings were due to habitat modification; even fluctuating asymmetry was not evident in insectivorous birds as had advocated Anciães &

Marini (2000). The high level of fluxes of the mist-netted bird community among the studied habitats could also explain the unclear conclusions obtained on fluctuating asymmetry. We also suggest that the higher food availability found in modified habitats attracts many forest birds and creates a higher competition for food and space, causing a reduction of territories and a reduction of body weight than in natural habitats.

SYNTHESIS AND CONCLUDING REMARKS

IX

SYNTHESIS AND CONCLUSION

In this concluding chapter, the main substances of our research were reviewed, from the analysis of various mist-netted bird guilds/groups species richness, abundance and structure along a gradient of forest disturbance, to the trial to understand the observed trends by analysing habitat factors relevant for birds. Then, some implications for the conservation of biodiversity in Afro-tropical forest ecosystems are derived.

IX.1. Mist-netted bird species richness, abundance and structure

Interpreting presence/absence data should be done with caution (Hughes *et al.* 2002) as understorey birds data showed different patterns from that of call-based method on the same plots (Waltert *et al.* 2005b), particularly at small scales. Even though low biodiversity of many taxa is usually found in land use systems, understorey birds might surprisingly be more diverse and abundant in disturbed habitats as in the present case study, except for the groups of ant-following birds and medium-sized foliage gleaners that seemed to be more vulnerable to disturbance. Thus land use systems, particularly when some fallow lands and trees are maintained in the agricultural matrix and when the pristine forest is not far as in our case study, could play an important role in the conservation of forest bird species, especially understorey ones. Also land use habitats seemed to be closer to natural habitats as far as abundance distribution is concerned, except for agroforestry systems. Species with smaller geographic range and larger body mass preferred the near-primary forest habitat. Species usually found at canopy level shifted to the understorey in annual croplands. While, insectivores preferred natural habitats, granivores, omnivores and frugivores preferred land use systems. If the number of captured individuals could be reliable determinant for the habitat quality of understorey bird in tropical rainforests as it was done in other studies (see Schemske & Brokaw 1981, Levey 1988, Lambert 1992), then all our studied habitats should be of almost the same quality and near-primary forest could be of the lowest quality. But,

capture rates should be interpreted with great caution as in territorial species under high population pressure, capture rates can be much higher in sub-optimal habitats than in optimal habitats (e.g. Waltert 2000a). And, in a complex habitat mosaic, even an inverse relationship between relative abundance and habitat quality may exist due to higher movement rates of sub-ordinate individuals (Winker *et al.* 1995). This might be the case in our study area. We advocated that degraded habitats temporally play as feeding places for many forest birds, outside their normal territories, particularly at period of food scarcity. Also, understorey birds seemed to have a great ability to disperse through deforested habitats, thus explaining their low habitat specificity. This ability has been found for understorey insectivorous birds in forest fragments of Las Cruces, southern Costa Rica (Şekercioğlu *et al.* 2002). Let us then analyse habitat factors relevant for birds in the following sections.

IX.2. Nest predation risk and availability of cavity nesting sites

As it is considered that the predator fauna detect and respond to artificial nests in a manner similar to natural nests (Martin 1987, Gibbs 1991, Carlson & Hartman 2001), the first nest types have also been used to predict real predation patterns in our study area although the selection of nesting sites plays a great role in the nest predation probability (Collias & Collias 1984). We found that nest loss is much lower in our study area compared to other tropical forest regions (e.g. Ricklefs 1969, Skutch 1985, Martin 1996, Pangau-Adam *et al.* 2006). This could mean that our avian breeding success is better, but at least for some species the clutch size and number of nesting attempts in each breeding season (read Cody 1966, Ricklefs 1977) still need to be investigated before any definitive confirmation. There was no sensitive effect of habitat types on nests predation, and ground nests were more vulnerable than shrub nests particularly in modified habitats. Small mammals and reptiles were identified to be the most common predators. If dead trees are left in the agricultural matrix, land use systems can be of much higher values for cavity nesters than natural habitats. But, it is clear that natural habitats will still continue to be preferred by some species like Owls, Hornbills and Trogons to dig their nesting cavities.

IX.3. Food resources for birds, leaf litter area and weight

It was documented that, unlike fruits, flowers and seeds, invertebrates actively avoid insectivores and, as a result, insectivorous birds have evolved into many specialized niches

while also actively searching for invertebrates and seek preys in certain microhabitats (see Şekercioğlu *et al.* 2002). This might explain why we found that overall invertebrate abundance was strongly negatively correlated with ant-following bird species richness and abundance. This might also explain why we previously found that fruit feeding butterfly species richness and abundance were lowest in annual croplands (read Bobo *et al.* 2006b). So, a dynamic situation could exist between insectivores and invertebrates where the first ones are always running after the second ones. The food scarcity hypothesis (Ford *et al.* 1996, Burke & Nol 1998, Zarette *et al.* 2000) might explain at least partly the disappearance of some understorey birds, particularly insectivores, from natural forests in the Korup region. It should also be the case for birds that feed on fruits and/or flowers. In other words, the abundance of food resources (invertebrates, fruits and flowers) in our land use systems might largely explain the occurrence of some understorey forest birds in modified habitats (but read Rappole & Morton 1985, Burke & Nol 1998). For some understorey bird groups like ant-following and medium-sized foliage gleaner birds, to some extent pycnonotids also, their higher importance in natural habitats might be found in other reasons, maybe the microclimate hypothesis (Karr & Freeman 1983, Stratford & Stouffer 1999), or the habitat specificity hypothesis (Ford *et al.* 1996, Stratford & Stouffer 1999), or the limited dispersal hypothesis (Greenberg 1988, Canaday 1996) or a combination of these three hypotheses. Also, larger leaves of the secondary forest floor were found to have no particular negative effect on the foraging capacity of terrestrial insectivorous birds.

IX.4. Ectoparasites, fault bars, fluctuating asymmetry, body weight and adult territory owners

Considering parameters like body weight and fault bars, natural habitats could be of better quality for understorey birds compared to land use systems (but read e.g. Sodhi *et al.* 2005), . Land use systems could also be of a much better quality for understorey birds than natural habitats as far as parasite loads (but read e.g. Robinson 1989, McKay 2006) and adult territory owners (but read Pulliam *et al.* 1992, Winker *et al.* 1995, Dias 1996, Dranzoa 1998, Renner 2003) are concerned, but it was evident that territories in land use systems are much smaller in size than those in natural habitats as a result of higher abundance of food resources that might have attracted many forest bird species and individuals creating more intra and interspecific

competitions for space in modified habitats. Nonetheless, insectivore adult territory owners were more abundant in natural habitats than in modified habitats. With fluctuating asymmetry particularly on wings and/or tarsi of some species like Little Greenbul, Yellow-whiskered Greenbul and Olive Sunbird, evidence could be found on the higher habitat quality of near-primary forest (read also Zakharov & Graham 1992, Anciães & Marini 2000, Aparicio & Bonal 2002).

IX.5. Implications for conservation

IX.5.1. Biological aspects

The observed patterns described in former chapters, most of which presenting no clear defined patterns from natural to modified habitats, and the undoubted importance of understorey forest bird community in land use systems (as in Estrada *et al.* 1993, Merker & Mühlenberg 2000, Daily *et al.* 2001), might be the consequences of the low endemism that characterises the Guinea-Congolian rainforest area, as compared to other tropical lowland forest areas like the Neotropics, Indo-Malayan and Australian regions (Keast 1990, Stattersfield *et al.* 1998). This is generally accompanied by a low habitat specialisation, fewer specialisations in food and foraging techniques (Karr 1976, Keast 1990). We also advocated the advantages of the closeness of primary forest that had favoured great exchanges and fluxes among individuals and species of the studied habitats (read also MacArthur *et al.* 1972, Thiollay 1995, Greenberg *et al.* 1997b).

We also suspected a wildlife crisis in our study area as the forest has the physiognomy of an empty one (read Redford 1992, Ichikawa 2006). In fact, most large and medium-sized mammals are already very rare. Also, the total absence of traps, very old remainings of cartridges in primary forests and many old abandoned fence-traps in the secondary bushes are other signs of a critical wildlife or biological situation in our study area. Poaching activities are now concentrated on bats and big birds like raptors, turacos and hornbills, and on the remaining primates that the further decline of threatened ones was already documented (Waltert *et al.* 2002). This phenomenon is also known from most important forests worldwide (Redford 1992, Ichikawa 2006). Generally, after the removal of larger mammals, a considerable decrease in densities of large birds is expected in the near future. This will amplify the negative impacts on the forest structure as the ecological role of these fruit-eating

vertebrates as seed dispersers will progressively be interrupted (Redford 1992) and, an ecosystem disfunctionality may occur in the medium to long term.

Thus, to promote the maintenance of biological diversity and natural ecosystem integrity in human-dominated ecosystems, we proposed (1) to also keep the natural forest very close in order to create a sort of mosaic natural forest-land use systems as it is known from an ecotone zone with a succession of forest-savannah mosaic habitats, (2) to live between 15 and 20% of the original basal area, forest tree species, and dead trees in the agricultural matrix, (3) to avoid as much as possible clear cuttings of large areas and mono-specific plantations (e.g. palm trees, cocoa/coffee, bananas, ...), (4) to allow a fallow period of three to five years in annual croplands that is essential in order to create temporal favourable microclimate conditions suitable to attract many forest bird species (read also Thiollay 1995, Greenberg *et al.* 1997a, Greenberg *et al.* 1997b, Lawton *et al.* 1998, Greenberg *et al.* 2000, Daily *et al.* 2001, Hughes *et al.* 2002, Fjeldsa *et al.* 2004, Waltert *et al.* 2004a).

IX.5.2. Socio-economic aspects

Consequences and reasons of deforestation or forest depletion go far beyond biological aspects. Subsistence hunting is the first major cause of direct defaunation following the presence of humans in an area (Redford 1992). Nowadays with the exponential increase in bushmeat consumption, the phenomenon is becoming irreversible. The situation is also very serious in Korup area and in Cameroon in general where the structural adjustment programs (e.g. employment adjustment, wage reductions) of the early 1990s have caused a reflux of population from cities to the countryside that have accelerated the expansion of bushmeat trade and forest degradation (Sunderlin *et al.* 2000, Ichikawa 2006). Other forms of exploitation of forest resources, like legal and illegal logging, wild timber sawing and the extraction of non-timber forest products should also be considered. In fact in Cameroon, logging area expanded from 8% in 1959 to 76% of the total 20 million hectares of forest area in 1999 in order to compensate unpaid loans (Ichikawa 2006). Wild timber sawing has been identified as one major source of income in rural areas, and the informal sector represents 35.6% of the national production of sawn wood in Cameroon (Betti & Bobo submitted). The great dependence of local people to forest resources for their livelihood or the co-existence of forest-dwellers (e.g. Pygmies) with forests is another important element. The slash-and-burn farming and hunting which have been sustaining the livelihoods and cultures of the forest-

dwellers for centuries will perhaps exceed the level necessary for ensuring their sustainability, threatening to make their livelihoods unviable in the near future (e.g. Ichikawa 2001, 2006).

Thus, efforts should be done (1) to provide alternative sources of protein and income (through income generating activities) other than bushmeat, wood and non-wood forest products in order to keep the poaching and illegal or wild forest resources exploitation to a minimum level and to inverse the trend in biodiversity losses in our study area or in rural areas in general.

IX.5.3. Cultural aspects

In fact in our study area, birds are now heavily hunted particularly touracos, hornbills and eagles. Wings, head and tail of hunted birds are sold to local traditional doctors (read also Tchigio 2007). There is also an important trade of this bird parts between local hunters and Nigerians who are collecting and transferring these trophies to their country. For e.g. each head of touracos, eagles and hornbills costed 5,000 francs CFA; together both wings and tail of each of same birds species costed between 3,000 and 5,000 francs CFA depending on species. So, apart from traditional and ultural aspects, all comes back to poorness and income.

Thus, efforts should also be done (1) to minimise the phenomenon of using bird parts for cultural and traditional purposes; (2) the observed trade of bird parts between Nigerians and local hunters, which is gaining in importance, should be stopped as quickly as possible.

IX.5.4. Management aspects

Land use systems, particularly logging areas, should be managed in order to enable them continue providing services to satisfy the increasing human needs without expanding rapidly into natural habitats. Thus, (1) an increased conservation effort is necessary in order to prevent the overexploitation of large birds and to restore healthy population of larger wildlife. This, however, will need (2) a combination of increased commitment of both local administrative authorities and natural resource management committees, including traditional rulers, but also (3) ongoing assistance by international bodies through innovative funding mechanisms. Presently, conservation management in the Korup area is limited to activities of smaller NGOs, which have only a very small spatial impact on natural resource management.

IX.6. Conclusion

The higher abundance of food resources for overall understorey bird community in land use systems, as compared to natural habitats, might have created a great competition among individuals and species. Consequently, the body weight and the size of territories are smaller in land use systems than in natural habitats. The higher number of individuals and species infested with ectoparasites found in natural habitats might just reflect the closeness of disturbed habitats that favor great, maybe temporal, exchange and migration fluxes among birds in our study area. Thus, many forest bird species have been easily trapped in land use systems, outside their normal territories. This was evident with insectivores that showed higher number of adult territory owners in natural habitats than in modified habitats, but a higher number of captures in land use systems than in natural habitats. This could also be seen with the overall fluctuating asymmetry on wings, tarsi and tails that seemed not to be affected by habitat types. But, fluctuating asymmetry in tarsi and/or wings of some species like Olive Sunbird, Yellow-whiskered Greenbul and Little Greenbul, fault bars, cavity nesting sites for Owls, Trogons and Hornbills, and the number of adult territory owners of insectivores might be used as indicators of the higher quality of natural forests for birds. There is no evidence to conclude on the negative effects of leaf litter area and weight for ground foraging birds in secondary forest habitats. Habitat types did not affect nests predation, although ground nests were more affected than shrub nests. The reproductive success seemed to be considerable in our study area, thus we could expect smaller number of nesting attempts each breeding season, resulting in increasing clutch size. This should be considered for further research on birds in our study area. The observed patterns described in former chapters might also be different according to seasons; thus a comparative study during the main rainy season, although very difficult to organize practically due to heavy rainfall and road access problems known from our study area, is essential before drawing any definitive conclusion.

For long-term suitability of different land use systems for forest bird populations, the closeness of primary forest matters much. Between 15 and 20% of the original basal area and forest tree species, and death trees should be left in the agricultural matrix. Clear cuttings of large areas and mono-specific plantations (e.g. palm trees, cocoa/coffee, bananas, ...) should be avoided as much as possible. Three to five years of fallow period is also essential in order to create temporal microclimatic conditions suitable for many forest birds. Efforts should also be done to keep the poaching to a minimum level and to provide alternative sources of protein and income other than bushmeat in order to avoid a deficiency of large and medium-sized

mammals and birds that might create a disfunctionality of the whole ecosystem in the medium to long term. Efforts should also be done to minimise the phenomenon of using bird parts for cultural and traditional purposes, and to stop the observed trade of bird parts between Nigerians and local hunters. Land use systems, particularly logging areas, should be managed in order to enable them continue providing services to satisfy the increasing human needs without expanding rapidly into natural habitats.

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APPENDICES

Appendix V.1.

Appendix VII.1.

Appendix VII.2.

APPENDIX V.1.

Number of individuals per species (n) in each habitat and capture frequencies (proportion of captured individuals per species and habitat to the total number of individual captured). Sequence and nomenclature as in Borrow and Demey (2001). Species with significant responses to habitat type after sequential Bonferroni correction are highlighted in bold. Habitats are: near-primary forest (NF), secondary forest (SF), agroforestry systems (CF) and annual cultures (AC).

Family	Species	NF		SF		CF		AC		Total	$F_{3, 20}$	P
		n	Freq.	n	Freq.	n	Freq.	n	Freq.			
Accipitridae	African Goshawk	2	0.002	0	0.000	1	0.001	0	0.000	3	1.41	0.269091203
	Black Sparrow-Hawk	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
Columbidae	Blue-headed Wood-dove	0	0.000	0	0.000	3	0.002	0	0.000	3	2.14	0.126737796
	Blue-spotted Wood-dove	0	0.000	0	0.000	0	0.000	7	0.005	7	3.18	0.046244462
	Tamborine Dove	0	0.000	0	0.000	0	0.000	3	0.002	3	2.14	0.126737796
Cuculidae	Didrick Cuckoo	0	0.000	0	0.000	0	0.000	5	0.004	5	3.05	0.052388886
	Yellowbill	0	0.000	0	0.000	0	0.000	2	0.002	2	1.00	0.413251935
Strigidae	Sjöstedt's barred Owlet	1	0.001	0	0.000	0	0.000	0	0.000	1	1.00	0.413251935
Alcedinidae	Woodland Kingfisher	0	0.000	0	0.000	0	0.000	1	0.001	1	1.00	0.413251935
	African Dwarf Kingfisher	0	0.000	1	0.001	0	0.000	0	0.000	1	1.00	0.413251935
	African Pigmy Kingfisher	0	0.000	0	0.000	2	0.002	10	0.008	12	3.66	0.029956198
	White-bellied kingfisher	7	0.005	4	0.003	2	0.002	1	0.001	14	1.15	0.35420671
	Malachite Kingfisher	0	0.000	0	0.000	2	0.002	0	0.000	2	2.50	0.088843748
Meropidae	Black Bee-eater	0	0.000	2	0.002	0	0.000	0	0.000	2	1.00	0.413251935
	White-throated Bee-eater	0	0.000	0	0.000	0	0.000	2	0.002	2	1.00	0.413251935
Bucerotidae	White-tighed Hornbill	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
Capitonidae	Nacket-faced Barbet	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
	Speckled Thinkerbird	0	0.000	0	0.000	2	0.002	7	0.005	9	4.46	0.014919314
	Yellow-spotted Barbet	0	0.000	3	0.002	1	0.001	0	0.000	4	1.54	0.235437857
Indicatoridae	Spotted Honeyguide	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
	Thick-billed Honeyguide	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
	Least Honeyguide	1	0.001	0	0.000	1	0.001	0	0.000	2	0.67	0.582321206
	Willcocks's Honeyguide	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
Picidae	African Piculet	0	0.000	1	0.001	0	0.000	2	0.002	3	1.41	0.269091203
	Buff-spotted Woodpecker	0	0.000	2	0.002	0	0.000	0	0.000	2	1.00	0.413251935
Eurylaimidae	Rufous-sided Broadbill	0	0.000	1	0.001	0	0.000	0	0.000	1	1.00	0.413251935
Motacillidae	Long-billed Pipit	0	0.000	0	0.000	0	0.000	2	0.002	2	1.00	0.413251935
Pycnonotidae	Little Greenbul	2	0.002	26	0.020	82	0.063	56	0.043	166	10.81	0.000195239
	Little grey Greenbul	0	0.000	0	0.000	8	0.006	11	0.008	19	7.43	0.001561176
	Cameroon sombre Greenbul	0	0.000	1	0.001	0	0.000	0	0.000	1	1.00	0.413251935
	Yellow-whiskered Greenbul	15	0.011	63	0.048	50	0.038	13	0.010	141	5.19	0.008158168
	Sjöstedt's Honeyguide Greenbul	0	0.000	1	0.001	0	0.000	0	0.000	1	1.00	0.413251935
	Simple Leaflove	0	0.000	0	0.000	0	0.000	5	0.004	5	2.36	0.102164236
	Baumann's Greenbul	0	0.000	0	0.000	0	0.000	5	0.004	5	4.31	0.016881233
	Icterine Greenbul	22	0.017	10	0.008	2	0.002	0	0.000	34	11.87	0.000110162
	Xavier's Greenbul	5	0.004	6	0.005	0	0.000	0	0.000	11	7.07	0.002005235
	Red-tailed Bristlebill	9	0.007	8	0.006	2	0.002	0	0.000	19	2.03	0.142139031
	Lesser Bristlebill	28	0.021	24	0.018	9	0.007	1	0.001	62	10.76	0.000200486
	Eastern-bearded Greenbul	1	0.001	1	0.001	1	0.001	0	0.000	3	0.33	0.801347879
	Red-tailed Greenbul	3	0.002	13	0.010	3	0.002	1	0.001	20	4.73	0.01185158
	Common garden Bulbul	0	0.000	0	0.000	0	0.000	2	0.002	2	2.50	0.088843748

Turdidae	Western Nicator	0	0.000	0	0.000	2	0.002	12	0.009	14	6.35	0.003366203
	Forest Robin	42	0.032	37	0.028	13	0.010	4	0.003	96	23.97	7.88443E-07
	Blue-shouldered Robin-Chat	0	0.000	0	0.000	0	0.000	1	0.001	1	1.00	0.413251935
	Fire-crested Alethe	28	0.021	25	0.019	8	0.006	3	0.002	64	2.37	0.101313092
	Brown-chested Alethe	14	0.011	10	0.008	0	0.000	0	0.000	24	8.17	0.000953102
	White-tailed Ant-Thrush	8	0.006	7	0.005	3	0.002	1	0.001	19	1.97	0.151441678
Sylviidae	Rufous Flycatcher Thrush	0	0.000	1	0.001	1	0.001	0	0.000	2	0.67	0.582321206
	Grey Ground Thrush	0	0.000	2	0.002	0	0.000	0	0.000	2	2.50	0.088843748
	Chattering Cisticola	0	0.000	0	0.000	0	0.000	6	0.005	6	7.50	0.001489903
	Grey-backed Camaroptera	0	0.000	4	0.003	3	0.002	11	0.008	18	3.67	0.029518001
	Yellow-browed Camaroptera	1	0.001	0	0.000	0	0.000	3	0.002	4	2.86	0.06284424
	Olive-green Camaroptera	0	0.000	0	0.000	1	0.001	7	0.005	8	2.76	0.068706638
	Yellow Longbill	0	0.000	0	0.000	2	0.002	0	0.000	2	1.00	0.413251935
	Kemp's Longbill	0	0.000	0	0.000	1	0.001	1	0.001	2	0.67	0.582321206
	Grey Longbill	1	0.001	3	0.002	7	0.005	0	0.000	11	1.51	0.242719414
	Green Crombec	0	0.000	0	0.000	0	0.000	13	0.010	13	7.48	0.001512482
Muscicapidae	Green Hylia	3	0.002	3	0.002	6	0.005	6	0.005	18	0.77	0.52470126
	White-browed Forest Flycatcher	0	0.000	1	0.001	0	0.000	0	0.000	1	1.00	0.413251935
	Grey-throated Tit Flycatcher	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
	Grey Tit Flycatcher	0	0.000	2	0.002	0	0.000	0	0.000	2	1.00	0.413251935
Monarchidae	Blue-headed crested Flycatcher	10	0.008	9	0.007	1	0.001	0	0.000	20	1.91	0.160266239
	Rufous-vented Paradise Flycatcher	0	0.000	2	0.002	3	0.002	3	0.002	8	0.80	0.508404647
	Red-bellied paradise Flycatcher	1	0.001	3	0.002	1	0.001	1	0.001	6	0.83	0.491260365
Platysteiridae	Chestnut Wattle-eye	1	0.001	5	0.004	5	0.004	0	0.000	11	1.84	0.171635042
	White-spotted Wattle-eye	1	0.001	1	0.001	0	0.000	0	0.000	2	0.67	0.582321206
	Red-checked Wattle-eye	2	0.002	0	0.000	4	0.003	3	0.002	9	0.48	0.698429948
	Yellow-bellied Wattle-eye	3	0.002	0	0.000	0	0.000	0	0.000	3	5.00	0.009510338
Timaliidae	Pale-breasted Illadopsis	28	0.021	9	0.007	1	0.001	0	0.000	38	20.28	2.79714E-06
	Brown Illadopsis	0	0.000	5	0.004	0	0.000	0	0.000	5	3.05	0.052388886
	Black-capped Illadopsis	7	0.005	3	0.002	0	0.000	0	0.000	10	4.40	0.015640732
Nectariniidae	Little green Sunbird	0	0.000	0	0.000	2	0.002	1	0.001	3	1.41	0.269091203
	Fraser's Sunbird	1	0.001	0	0.000	0	0.000	0	0.000	1	1.00	0.413251935
	Olive Sunbird	24	0.018	42	0.032	71	0.054	32	0.024	169	8.46	0.000793119
	Collared Sunbird	0	0.000	0	0.000	0	0.000	3	0.002	3	5.00	0.009510338
	Olive-bellied Sunbird	0	0.000	0	0.000	3	0.002	30	0.023	33	5.46	0.006575341
	Tiny Sunbird	0	0.000	0	0.000	0	0.000	2	0.002	2	2.50	0.088843748
	Variable Sunbird	0	0.000	0	0.000	0	0.000	1	0.001	1	1.00	0.413251935
	Johanna's Sunbird	0	0.000	2	0.002	1	0.001	1	0.001	4	0.74	0.540197014
	Superb Sunbird	0	0.000	0	0.000	0	0.000	2	0.002	2	2.50	0.088843748
	Splendid Sunbird	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
Malaconotidae	Sooty Boubou	0	0.000	0	0.000	0	0.000	1	0.001	1	1.00	0.413251935
Dicruridae	Shining Drongo	0	0.000	1	0.001	0	0.000	0	0.000	1	1.00	0.413251935
Ploceidae	Black-necked Weaver	0	0.000	0	0.000	0	0.000	5	0.004	5	4.31	0.016881233
	Vieillot's black Weaver	0	0.000	0	0.000	0	0.000	1	0.001	1	1.00	0.413251935
	Village weaver	0	0.000	0	0.000	0	0.000	3	0.002	3	1.00	0.413251935
	Crested Malimbe	0	0.000	0	0.000	1	0.001	0	0.000	1	1.00	0.413251935
Estrildidae	Red-headed Ant-pecker	3	0.002	4	0.003	0	0.000	0	0.000	7	1.31	0.299541249
	Grey-crowned Negrofinch	0	0.000	0	0.000	0	0.000	3	0.002	3	2.14	0.126737796
	Chestnut-breasted Negrofinch	0	0.000	0	0.000	0	0.000	4	0.003	4	1.82	0.17632219
	Western Bluebill	5	0.004	6	0.005	4	0.003	23	0.018	38	8.25	0.000906578
	Green Twinspot	0	0.000	0	0.000	4	0.003	4	0.003	8	1.67	0.206121652
	Black and white Mannikin	0	0.000	0	0.000	0	0.000	20	0.015	20	1.13	0.361271456
Total individuals		279	0.214	354	0.275	327	0.257	347	0.269	1307	/	/
Total species		31	0.33	41	0.44	48	0.52	51	0.55	93	/	/

APPENDIX VII.1.

Leaf area (cm²) of corresponding tree/plant species in different habitat types. Mean \pm Standard Deviations are given. Results of One-way ANOVA are also presented. In bold are species that leaf areas are nearly or significantly different between habitat types. Habitats are: near-primary forest (NF), secondary forest (SF), agroforestry systems (CF) and annual cultures (AC). Valid tree/plant species names follow mainly the Missouri Botanical Garden's VAST ([VAScular Tropicos](#)) nomenclatural database.

Species	NF		SF		CF		AC		F	P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
<i>Afzelia bella</i>	134.0	/	/	/	/	/	/	/	/	/
<i>Albizia</i> sp.	/	/	/	/	/	/	20.1	/	/	/
<i>Albizia zygia</i>	/	/	/	/	/	/	17.2	4.1	/	/
<i>Alchornea longiflora</i>	/	/	/	/	/	/	97.2	8.3	/	/
<i>Alstonia boonei</i>	91.3	/	95.0	40.3	100.4	20.9	67.8	16.1	1.33	0.3247
<i>Anthonotha macrophyla</i>	138.0	21.2	/	/	/	/	/	/	/	/
<i>Aspilia africana</i>	/	/	/	/	/	/	75.6	0.0	/	/
<i>Baillonella toxisperma</i>	90.7	/	152.3	45.0	191.2	/	/	/	1.28	0.5306
<i>Baphia nitida</i>	/	/	81.6	30.5	73.6	16.3	100.7	28.0	0.87	0.4669
<i>Barteria fistulosa</i>	354.6	/	215.9	17.5	/	/	122.3	/	45.04	0.0018
<i>Belonophora</i> sp.	/	/	/	/	/	/	84.2	/	/	/
<i>Berlinia brateosa</i>	150.1	78.7	112.7	42.3	/	/	/	/	0.36	0.5932
<i>Berlinia</i> sp.	72.9	/	/	/	/	/	/	/	/	/
<i>Blighia</i> sp.	146.6	28.9	/	/	/	/	/	/	/	/
<i>Bridelia micrantha</i>	/	/	/	/	/	/	109.3	/	/	/
<i>Bryopsis</i> sp.	595.5	/	/	/	/	/	/	/	/	/
<i>Calycosiphonia</i> sp.	/	/	/	/	/	/	169.8	/	/	/
<i>Calpocalyx</i> sp.	75.0	/	/	/	/	/	/	/	/	/
<i>Canarium schweinfurtii</i>	60.0	/	/	/	/	/	/	/	/	/
<i>Carapa grandiflora</i>	240.9	/	128.1	98.4	/	/	/	/	0.99	0.4255
<i>Carpolobia lutea</i>	37.5	/	/	/	/	/	/	/	/	/
<i>Ceiba pentandra</i>	/	/	46.9	/	/	/	/	/	/	/
<i>Chromolaena odorata</i>	/	/	/	/	/	/	48.1	8.3	/	/
<i>Coffea robusta</i>	/	/	85.1	/	148.1	19.4	131.5	43.4	2.48	0.1790
<i>Cola acuminata</i>	359.0	/	/	/	/	/	/	/	/	/
<i>Cola chlamydantha</i>	249.5	81.8	/	/	/	/	/	/	/	/
<i>Cola lepidota</i>	/	/	332.5	47.4	255.8	16.0	/	/	4.69	0.1627
<i>Cola nitida</i>	/	/	133.9	41.2	152.1	40.8	66.9	5.5	5.78	0.0502
<i>Cola</i> sp.	/	/	202.2	60.3	/	/	/	/	/	/
<i>Cordia cordifolia</i>	/	/	195.0	/	/	/	/	/	/	/
<i>Costus afer</i>	/	/	/	/	/	/	145.5	65.3	/	/
<i>Cynometra</i> sp.	29.4	/	/	/	/	/	/	/	/	/
<i>Dacryodes edulis</i>	/	/	90.6	21.7	105.2	19.6	85.3	16.3	1.43	0.2845

<i>Dacryodes klaineana</i>	56.1	/	/	/	/	/	/	/	/	/
<i>Dioscorea sp.</i>	/	/	/	/	/	/	123.0	32.6	/	/
<i>Draceana surculosa</i>	/	/	/	/	/	/	95.5	/	/	/
<i>Distemonanthus benthamianus</i>	70.3	/	/	/	/	/	/	/	/	/
<i>Enanthia chloranta</i>	/	/	97.0	12.7	/	/	/	/	/	/
<i>Entandrophragma cylindricum</i>	95.8	/	/	/	/	/	/	/	/	/
<i>Erythrophleum ivorense</i>	20.3	/	/	/	/	/	/	/	/	/
<i>Ficus exasperata</i>	/	/	/	/	/	/	98.4	12.1	/	/
<i>Ficus winkleri</i>	176.8	/	109.9	37.6	103.0	/	95.0	/	1.05	0.4838
<i>Funtumia elastica</i>	113.9	/	115.8	6.8	109.1	33.0	73.2	22.3	1.78	0.2285
<i>Gambeya africana</i>	127.6	14.6	122.3	92.8	/	/	/	/	0.01	0.9431
<i>Garcinia mannii</i>	34.4	11.0	59.6	/	/	/	/	/	3.93	0.1859
<i>Garcinia staudtii</i>	72.8	13.7	/	/	/	/	/	/	/	/
<i>Gilbertiodendron dewevrei</i>	172.0	/	/	/	/	/	/	/	/	/
<i>Grewia coriacea</i>	/	/	/	/	/	/	73.0	10.7	/	/
<i>Homalium longistylum</i>	157.5	46.5	182.3	83.0	/	/	/	/	0.15	0.7164
<i>Hyloidendron gabunense</i>	41.9	6.5	49.9	14.1	/	/	44.1	/	0.27	0.7864
<i>Hypodaphnis zenkeri</i>	156.7	/	172.6	41.3	/	/	/	/	0.12	0.7541
<i>Ipomoea batatas</i>	/	/	/	/	/	/	91.0	/	/	/
<i>Irvingia gabonensis</i>	/	/	/	/	50.1	5.0	41.2	9.5	1.48	0.2775
<i>Irvingia wombolu</i>	/	/	/	/	/	/	50.2	/	/	/
<i>Keayodendron sp.</i>	/	/	/	/	/	/	116.9	16.0	/	/
<i>Klainedoxa gabonensis</i>	/	/	225.1	26.4	/	/	/	/	/	/
<i>Lophira alata</i>	125.0	87.5	212.3	86.4	106.7	/	130.8	/	0.72	0.5824
<i>Macaranga monandra</i>	/	/	63.2	/	147.2	/	146.8	21.3	5.78	0.2821
<i>Maesobotrya dusenii</i>	104.0	/	/	/	/	/	/	/	/	/
<i>Mangifera indica</i>	/	/	/	/	142.6	9.9	117.0	73.6	0.21	0.6746
<i>Manihot esculenta</i>	/	/	/	/	/	/	116.9	38.1	/	/
<i>Microdesmis puberula</i>	/	/	/	/	/	/	56.9	/	/	/
<i>Myrianthus arborea</i>	/	/	/	/	214.5	/	107.9	/	/	/
<i>Morinda lucida</i>	187.2	/	125.8	23.0	/	/	171.7	/	2.82	0.3881
<i>Musanga cecropioides</i>	141.7	41.4	125.8	12.7	183.6	4.9	76.1	/	5.47	0.0671
<i>Nauclea diderrichii</i>	302.0	/	/	/	/	/	/	/	/	/
<i>Oubanguia alata</i>	75.6	7.5	/	/	/	/	/	/	/	/
<i>Palisota ambigua</i>	/	/	/	/	/	/	123.8	/	/	/
<i>Persea americana</i>	/	/	145.6	/	111.3	29.2	97.4	36.6	0.87	0.4671
<i>Poga oleosa</i>	54.4	16.6	32.3	/	/	/	/	/	1.19	0.4724
<i>Protomegabaria stapfiana</i>	224.7	142.1	/	/	/	/	/	/	/	/
<i>Pueraria sp.</i>	/	/	/	/	/	/	37.7	/	/	/
<i>Pycnanthus angolensis</i>	186.0	48.9	186.2	36.2	142.4	52.5	/	/	1.15	0.3564
<i>Rauvolfia vomitoria</i>	/	/	/	/	/	/	81.2	11.1	/	/
<i>Ricinodendron heudelotii</i>	/	/	92.6	/	132.2	67.5	107.5	29.1	0.30	0.7626
<i>Rothmannia hispida</i>	/	/	75.5	/	/	/	/	/	/	/
<i>Santiria balsamifera</i>	75.7	21.5	/	/	/	/	/	/	/	/
<i>Staudtia kamerunensis</i>	107.0	/	/	/	/	/	/	/	/	/
<i>Strombosia grandifolia</i>	149.8	39.7	137.4	26.1	/	/	/	/	0.19	0.6942
<i>Strychnos congolana</i>	90.4	/	/	/	/	/	/	/	/	/
<i>Tabernaemontana brachyantha</i>	117.2	/	297.3	192.0	/	/	/	/	0.70	0.4630
<i>Terminalia superba</i>	45.8	/	41.3	4.9	52.6	7.8	40.0	3.1	3.66	0.0716
<i>Theobroma cacao</i>	/	/	179.3	15.0	198.1	16.3	168.6	26.1	2.75	0.1166
<i>Treculia africana</i>	97.5	29.3	/	/	172.2	/	/	/	4.86	0.1583
<i>Treculia obovoidea</i>	98.4	6.7	/	/	127.0	/	/	/	/	/
<i>Treculia sp.</i>	/	/	203.4	/	/	/	/	/	/	/
<i>Trichilia rubescens</i>	104.6	/	/	/	77.8	/	/	/	/	/

<i>Triumpheta cordifolia</i>	/	/	/	/	/	/	59.7	/	/	/
<i>Uapaca guineensis</i>	111.8	54.7	200.8	127.2	/	/	/	/	1.69	0.2298
<i>Vitex ferruginea</i>	44.2	/	/	/	/	/	/	/	/	/
<i>Vitex grandifolia</i>	/	/	247.5	/	/	/	287.1	/	/	/
<i>Voacanga africana</i>	/	/	164.3	/	/	/	/	/	/	/
<i>Unknown 1</i>	/	/	53.3	/	/	/	/	/	/	/
<i>Unknown 2</i>	63.4	/	67.8	/	/	/	/	/	/	/
<i>Unknown 3</i>	/	/	/	/	/	/	152.6	14.0	/	/
Mean	126.1	30.8	150.3	23.4	151.0	18.6	89.9	7.8	10.39	0.0002

APPENDIX VII.2.

Leaf weight (g) of corresponding tree/plant species in different habitat types. Mean \pm Standard Deviations are given. Results of One-way ANOVA are also presented. In bold are species that leaf weights are nearly or significantly different between habitat types. Habitats are: near-primary forest (NF), secondary forest (SF), agroforestry systems (CF) and annual cultures (AC). Valid tree/plant species names follow mainly the Missouri Botanical Garden's VAST ([VAScular Tropicos](#)) nomenclatural database.

Species	NF		SF		CF		AC		F	P
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
<i>Afzelia bella</i>	4.00	/	/	/	/	/	/	/	/	/
<i>Albizia</i> sp.	/	/	/	/	/	/	0.10	/	/	/
<i>Albizia zygia</i>	/	/	/	/	/	/	0.12	0.03	/	/
<i>Alchornea longiflora</i>	/	/	/	/	/	/	1.29	0.64	/	/
<i>Alstonia boonei</i>	1.35	/	1.54	1.01	1.96	0.51	1.41	0.36	0.73	0.562004
<i>Anthonotha macrophyla</i>	1.96	1.36	/	/	/	/	/	/	/	/
<i>Aspilia africana</i>	/	/	/	/	/	/	1.12	0.15	/	/
<i>Baillonella toxisperma</i>	3.27	/	3.17	1.89	2.80	/	/	/	0.02	0.982601
<i>Baphia nitida</i>	/	/	1.52	0.73	0.83	0.25	0.64	0.21	4.31	0.069024
<i>Barteria fistulosa</i>	6.94	/	5.79	0.78	/	/	2.35	/	10.14	0.027144
<i>Belanophora</i> sp.	/	/	/	/	/	/	0.65	/	/	/
<i>Berlinia brateosa</i>	4.35	2.75	2.60	0.94	/	/	/	/	0.68	0.468579
<i>Berlinia</i> sp.	1.05	/	/	/	/	/	/	/	/	/
<i>Blighia</i> sp.	0.94	0.09	/	/	/	/	/	/	/	/
<i>Bridelia micrantha</i>	/	/	/	/	/	/	0.83	/	/	/
<i>Bryopsis</i> sp.	14.00	/	/	/	/	/	/	/	/	/
<i>Calycosiphonia</i> sp.	/	/	/	/	/	/	4.00	/	/	/
<i>Calpocalyx</i> sp.	2.00	/	/	/	/	/	/	/	/	/
<i>Canarium schweinfurtii</i>	1.03	/	/	/	/	/	/	/	/	/
<i>Carapa grandiflora</i>	2.00	/	5.49	3.03	/	/	/	/	0.99	0.423794
<i>Carpolobia lutea</i>	0.50	/	/	/	/	/	/	/	/	/
<i>Ceiba pentandra</i>	/	/	1.00	/	/	/	/	/	/	/
<i>Chromolaena odorata</i>	/	/	/	/	/	/	0.44	0.17	/	/
<i>Coffea robusta</i>	/	/	1.35	/	1.72	0.31	1.03	0.04	4.73	0.070283
<i>Cola acuminata</i>	9.50	/	/	/	/	/	/	/	/	/
<i>Cola chlamydantha</i>	10.13	0.88	/	/	/	/	/	/	/	/
<i>Cola lepidota</i>	/	/	4.19	1.68	3.53	0.19	/	/	0.30	0.639006
<i>Cola nitida</i>	/	/	2.55	0.39	3.44	0.59	1.02	0.24	22.98	0.003015
<i>Cola</i> sp.	/	/	3.85	2.20	/	/	/	/	/	/
<i>Cordia cordifolia</i>	/	/	5.10	/	/	/	/	/	/	/
<i>Costus afer</i>	/	/	/	/	/	/	4.27	3.16	/	/
<i>Cynometra</i> sp.	0.14	/	/	/	/	/	/	/	/	/
<i>Dacryodes edulis</i>	/	/	1.41	0.57	1.79	0.51	1.47	0.48	0.72	0.511730

<i>Dacryodes klaineana</i>	1.46	/	/	/	/	/	/	/	/	/
<i>Dioscorea sp.</i>	/	/	/	/	/	/	1.57	0.71	/	/
<i>Draceana sulculosa</i>	/	/	/	/	/	/	0.63	/	/	/
<i>Distemonanthus benthamianus</i>	1.13	/	/	/	/	/	/	/	/	/
<i>Enanthia chloranta</i>	/	/	1.09	0.58	/	/	/	/	/	/
<i>Entandrophragma cylindricum</i>	1.33	/	/	/	/	/	/	/	/	/
<i>Erythrophleum ivorense</i>	0.35	/	/	/	/	/	/	/	/	/
<i>Ficus exasperata</i>	/	/	/	/	/	/	1.28	0.24	/	/
<i>Ficus winkleri</i>	3.50	/	2.06	0.75	1.01	/	1.00	/	2.51	0.234726
<i>Funtumia elastica</i>	2.00	/	2.38	0.25	1.91	0.90	1.53	0.98	0.43	0.734883
<i>Gambeya africana</i>	2.44	2.03	1.87	1.42	/	/	/	/	0.11	0.776218
<i>Garcinia mannii</i>	0.71	0.36	1.00	/	/	/	/	/	0.49	0.556977
<i>Garcinia staudtii</i>	1.71	0.50	/	/	/	/	/	/	/	/
<i>Gilbertiodendron dewevrei</i>	3.23	/	/	/	/	/	/	/	/	/
<i>Grewia coriacea</i>	/	/	/	/	/	/	0.86	0.24	/	/
<i>Homalium longistylum</i>	5.31	3.80	4.53	1.75	/	/	/	/	0.16	0.702969
<i>Hylodendron gabunensis</i>	0.70	0.04	0.55	0.64	/	/	0.20	/	0.41	0.710786
<i>Hypodalpnis zenkeri</i>	1.34	/	2.92	0.69	/	/	/	/	4.25	0.131333
<i>Ipomoea batatas</i>	/	/	/	/	/	/	2.00	/	/	/
<i>Irvingia gabonensis</i>	/	/	/	/	0.84	0.05	0.48	0.22	4.87	0.078497
<i>Irvingia wombolu</i>	/	/	/	/	/	/	1.02	/	/	/
<i>Kaeyodendron sp.</i>	/	/	/	/	/	/	1.55	0.37	/	/
<i>Klainedoxa gabonensis</i>	/	/	4.71	3.29	/	/	/	/	/	/
<i>Lophira alata</i>	2.06	0.93	3.46	1.69	1.00	/	1.00	/	1.54	0.312849
<i>Macaranga monandra</i>	/	/	1.00	/	0.95	/	1.29	0.42	0.30	0.791567
<i>Maesobotrya dusenii</i>	3.05	/	/	/	/	/	/	/	/	/
<i>Mangifera indica</i>	/	/	/	/	2.44	0.20	1.61	1.03	1.15	0.361754
<i>Manihot esculenta</i>	/	/	/	/	/	/	2.38	1.16	/	/
<i>Microdermis puberula</i>	/	/	/	/	/	/	0.57	/	/	/
<i>Myrianthus arborea</i>	/	/	/	/	2.37	/	1.18	/	/	/
<i>Morinda lucida</i>	2.50	/	2.38	0.10	/	/	3.04	/	14.36	0.183424
<i>Musanga cecropioides</i>	4.52	1.15	2.59	0.51	2.62	0.54	1.20	/	5.29	0.070643
<i>Nauclea diderrichii</i>	6.00	/	/	/	/	/	/	/	/	/
<i>Oubanguia alata</i>	1.76	0.29	/	/	/	/	/	/	/	/
<i>Palisota ambigua</i>	/	/	/	/	/	/	3.50	/	/	/
<i>Persea americana</i>	/	/	2.68	/	1.31	0.74	1.51	0.61	1.66	0.267158
<i>Poga oleosa</i>	1.58	0.32	1.13	/	/	/	/	/	1.28	0.460267
<i>Protomegabaria stapfiana</i>	5.89	5.49	/	/	/	/	/	/	/	/
<i>Pueraria sp.</i>	/	/	/	/	/	/	0.73	/	/	/
<i>Pycnanthus angolensis</i>	5.46	0.57	5.81	1.34	4.11	1.71	/	/	1.87	0.204434
<i>Rauvolfia vomitoria</i>	/	/	/	/	/	/	1.60	0.57	/	/
<i>Ricinodendron heudelotii</i>	/	/	2.13	/	1.67	0.05	1.39	0.47	1.40	0.371082
<i>Rothmania hispida</i>	/	/	0.80	/	/	/	/	/	/	/
<i>Santiria balsamifera</i>	1.07	1.05	/	/	/	/	/	/	/	/
<i>Staudtia kamerunensis</i>	1.00	/	/	/	/	/	/	/	/	/
<i>Strombosia grandifolia</i>	3.82	1.44	2.39	0.20	/	/	/	/	3.40	0.162465
<i>Strychnos congolana</i>	1.63	/	/	/	/	/	/	/	/	/
<i>Tabernaemontana brachyantha</i>	1.21	/	6.64	3.98	/	/	/	/	1.49	0.309532
<i>Terminalia superba</i>	0.50	/	0.80	0.16	0.95	0.05	0.73	0.23	1.93	0.212755
<i>Theobroma cacao</i>	/	/	1.90	0.61	1.72	0.23	2.07	0.90	0.44	0.659332
<i>Treculia africana</i>	1.89	1.58	/	/	1.40	/	/	/	0.07	0.813901
<i>Treculia obovoidea</i>	1.31	0.25	/	/	1.00/	/	/	/	/	/
<i>Treculia sp.</i>	/	/	5.97	/	/	/	/	/	/	/
<i>Trichilia rubescens</i>	1.07	/	/	/	1.20	/	/	/	/	/

<i>Triumpheta cordifolia</i>	/	/	/	/	/	/	/	0.84	/	/	/
<i>Uapaca guineensis</i>	3.10	1.56	4.63	3.28	/	/	/	/	/	0.74	0.415428
<i>Vitex ferruginea</i>	0.30	/	/	/	/	/	/	/	/	/	/
<i>Vitex grandifolia</i>	/	/	4.50	/	/	/	/	13.50	/	/	/
<i>Voacanga africana</i>	/	/	4.50	/	/	/	/	/	/	/	/
<i>Unknown 1</i>	/	/	0.84	/	/	/	/	/	/	/	/
<i>Unknown 2</i>	0.92	/	0.83	/	/	/	/	/	/	/	/
<i>Unknown 3</i>	/	/	/	/	/	/	/	1.21	0.31	/	/
Mean	2.92	0.82	3.30	0.58	1.81	0.18	1.30	0.24	19.21	0.000004	

ABOUT THE AUTHOR

Born in April 1970, BOBO Kadiri Serge grew up in Douala, the economic capital of Cameroon in Central Africa. He accomplished his secondary education in a Protestant College at Mbo/Bandjoun near Bafoussam, the West provincial main city, in 1988 when he entered the National Advanced School of Agriculture in Dschang (Cameroon).

In 1994, BOBO graduated in Forestry, as an “Ingénieur des Eaux, Forêts et Chasses”, at the Dschang University. He did majors in animal ecology and management with focus on fish and fisheries at the Forestry School in Mbalmayo and at the Mbakaou hydroelectric dam near Tibati (Cameroon). This was its first experience in natural resources assessment and management problems. This has introduced him to the challenges in working with local communities, traditional and administrative authorities.

During the first five years of his professional career, Bobo was active in the ecological rehabilitation of the Waza-Logone floodplain in the Far-North of Cameroon that was drought out by the construction of an upstream hydro-agricultural dam for the irrigation of a rice scheme. He was the ecological counterpart of the IUCN/Waza-Logone project from 1995 to 1997 and was more concerned with waterbird, vegetation, fish/fishery and wildlife surveys. He headed the ecological research section of the Waza-Logone project from 1997 to early 1999, and supervised impact studies of reflooding on vegetation, wildlife, fish/fishery, Waterbirds in the Logone floodplain and in the Waza National Park. Employed by BirdLife International/Yaounde, from early 1999 to end 2000, Bobo coordinated the Important Bird Areas (IBA) programme in Cameroon and, realised and supervised most of the bird field surveys throughout the country and the identification of IBAs.

In 2001, Bobo was appointed as the Conservator of the newly created Mbam and Djerem National Park (Cameroon) where he left in mid 2002 for a two years Master programme in “Tropical and International Forestry” at the Georg-August-University of Göttingen in Germany thanks to the DAAD scholarship. In 2005, Bobo started a PhD programme at the Department of Conservation Biology, Centre for Nature Conservation, Georg-August-University of Göttingen, and the present thesis is aimed to conclude this academic level.

In 2006, Bobo did his military service and is now harboring the grade of Lieutenant Colonel in the Forest and Wildlife Corps.

During his free times, Bobo is a consultant and did many works for WWF-CARPO, BirdLife International, GTZ, European Union/CEF and Ministry of Forest and Wildlife/PSFE. Bobo's main interests are Forest, Savannah and Wetland ecology and management, Ornithological studies, Multi-resources Surveys (birds, butterflies, plants, trees, fishes, invertebrates), Sustainable forest and wildlife management and Certification, Land use effects on biodiversity, Biodiversity and indicator's properties, Formulation of management plans for national parks and sport hunting areas.

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Bobo's consultancy works, the Centre for Nature Conservation - Georg-August-University of Göttingen in Germany and the German Society for Tropical Ornithology (GTO) sponsored this thesis.

ACKNOWLEDGMENTS

For the financial assistance of the production of this thesis, I am grateful to the efforts of Dr. Matthias Waltert and Prof. Michael Mühlenberg from Centre of Nature Conservation, Georg-August-University of Göttingen, and to Dr. Christoph Hinkelmann from GTO. Dr. Matthias Waltert assisted also with the language editing and revision of the thesis, Thorsten Späth with the German translation of the Summary.

I am grateful to my promoters Prof. Dr. Michael Mühlenberg and Prof. Dr. Rainer Willmann for the thesis review. I am also grateful to the staff and students of the Centre for Nature Conservation, Georg-August-University of Göttingen, Dr. Matthias Waltert, Dr. Eckhard Gottschalk, Dr. Jolanta Slowik, Dr. Hondong Hermann, Dr. Dulamsuren Choimaa, Dr. Margaretha Pangau-Adam, Dr. Mei-Ling Bai and Thorsten, Dr. Innocent Tchigio and Jeanne d'Arc, Dr. Meeske Martina, Dr. Indra Yustian, Christos Astaras, Kamini Kusum Barua, Anna Kemmling, Werner Beeke, Elisabeth Opielka, Monika Deseniß, Andrea Lambertz, for their support during my stay at the Centre.

Our sincere thanks to Dr. Volker Dinse, Sven Baumon and Kirsten Heyer from the "Reit" ringing station in Hamburg and to Dr. Ulrich Querner from the Radolfzell ringing station, for providing the mist-nests. I had wonderful moments with the bird ringing team at the "Reit" station in Bergedorf (Hamburg) during my volunteer works, particularly with Volker Dinse, Daniel Kissling, Haus-Jürgen Lade, Holger Meinig, Kirsten Heyer, Horst and Sven Baumon.

I had convivial times with Thorsten Späth and Mei-Ling in Braunschweig and in the Harz National Park, Margaretha, Duja and Markus Hauck, Jolanta Slowik, Emelda Lum, Innocent and Jeanne d'Arc Tchigio, Matthias Waltert, Ghislain Kouematchoua and his late wife, Tomté Edmond and Loris, Chicgoua Noubactep, Jacob Souopgui, Liliane and Julia Ziniewitz in Göttingen, Djuikom Marthe and Michel Vandenberg in Kassel, Paul Scholte and Stephany in Amsterdam (The Netherlands), Nganou René and the family in Lille (France).

Many thanks to Dr. Uwe Betjen, Ghislain Kouematchoua, Massok Georges, Youmbi Peka Silas, Koutouzi Francis and Ndjebayi Banack-fils Edouard who did a great job and gave me great moral and psychological support during my difficult times in Germany.

I am grateful to the traditional councils of the villages Abat, Basu and Mgbegati for their co-operation and help. I am also grateful to my data collection field men Agbor Zach's and Bessong Michael from Ngbegati, Mbeng Eno Samuel, Arrey Samuel and Bechem Emilia from Abat, Njie M. Francis (*man, you are the best bird watcher ever known in our country*) from Limbe, Mengamenya Achille from MINFOF/Garoua, Joel Tougoulou, Armand Nzongang and David Zakandi, Arlette from Alpican/Grumcam in Mindourou, and late John Njokagbor from Ossing whose passing away is a great loss for the bio-monitoring in the Korup area.

I will never forget my friend of all times Mark van Dorp in Amsterdam (The Netherlands) and my colleagues foresters who encouraged me, Dr. Betti Jean Largarde, Prof. Weladji Robert Bertrand, Djogo Toumouksala and Guilaine (my 'souffle douleur'), Hebou Luc and Annick, Mbolo Daniel, Achanchou Valentine, Djabou Philomène, Symphorien Ongolo, Ayissi Mba, Essomba Henri II, Pandong Eitel, Pettang Jules Blaise, Gao Bouba, the Director Koulagna Koutou Denis and the Secretary General/MINFOF Dr. Madi Ali. Sincere thanks to Dr. Leonard Usongo and Dr. Tchamba Martin from WWF-CARPO, Didier Bastin from Alpican/Grumcam, Alain Nouredine from ECOFAC, Prof. Ngoufo Roger from CEW/Yaounde University, Martha Ebot Bechem from IUCN/MIKE, Chief-Sergeant Karinga Wappi, Mohamed and Emma from the Presidential Guard in Yaounde for their support and advises.

My parents, the army Commandant Bobo Jean Claude and Njandja Séraphine, have given me enough love and supported me to continue with my studies as far as possible. Thus, I am also advising and encouraging my younger brothers, particularly Robert, Cécile, Adeline, Martiale, Narcisse, Roger, Elie, Fernanda, René, to take this as a sign of courage and perseverance. My two little boys Bobo Alima Nasser Wilfried and Bobo Hamadjida Halilou Claude, and my future kids, are always in my heart and must see this modest work as an objective of their academic life to meet when ever possible. Anne Tchadzu has supported me with her great love and help.

The Cameroonian Ministry of Forest and Wildlife had allowed me to conduct this research and had supported my salary.

Lebenslauf

Name: Kadiri Serge BOBO
Geburtsdatum: 05.04.1970
Geburtsort: Douala
Familienstand: Geschieden
Nationalität: Kamerunisch

Ausbildung

1982: Zertifikat primärer und elementarer Studien, Koutaba, Kamerun
1986: Patent von Studien des ersten Zyklus, Bandjoun, Kamerun
1987: „Probatoire D Scientifique“, Bandjoun, Kamerun
1988: Abitur („Baccalaureat D“ Scientific), Bandjoun, Kamerun
1988-1994: Studium der Forstwirtschaft an der Universität Dschang, Kamerun, „Ingenieur des Eaux, Forêts et Chasses“
2002-2005: Studium der Tropischen und Internationalen Forstwirtschaft an der Georg-August-Universität Göttingen, Deutschland
Seit 2005: Promotionsstudium an der Georg-August-Universität Göttingen, Deutschland

Berufserfahrung

Seit 01/2001: Mitarbeiter am Kamerunischen Forstministerium „Ministère des Forêts et de la Faune- MINFOF“, Direktor Mbam & Djerem Nationalparks, am „Direction de la Faune et des Aires Protégées“ und am „Division de la Cooperation et des Projets“.
04/1999-12/2000: Koordinator des Programms „Important Bird Areas (IBA)“, Kamerun, BirdLife International.
09/1995-01/1999: Mitarbeiter am Waza-Logone Projekt/IUCN, Abteilung Ökologie, Kamerunischen Forstministerium.
12/1994-08/1995: Mitarbeiter am Kamerunischen Forstministerium „Délégation Provinciale du Nord“.

Göttingen, 13. September 2007