Biogeography of West African Gallery Forests

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Abstract

Gallery forests (GFs) are floristically and functionally distinct forests along rivers and watercourses. The GFs of the West African savannas form thin stripes with a particular, species-rich flora differing significantly from the surrounding vegetation. Due to their relative isolation in the savannas and their dependence on rivers, GFs are particularly endangered by the expected global climate changes in the 21st century. Despite their high diversity, little is known about the ecology and biogeography of GFs in West Africa. Especially, their response to climate changes and their vegetation dynamics remain largely unknown. This thesis combines floristic, phylogeographic and ecological data to investigate the biodiversity, historical and recent biogeography and conservation status of GF species in Burkina Faso (BFA) as a model for West Africa.

I) The GF flora and vegetation of BFA is still poorly understood. In section 3.1 species richness patterns of GFs in BFA were evaluated, and based on this data the diversity, taxonomical composition and functional diversity of the GF flora were analysed. Additionally, the economic importance of GFs for local human populations was evaluated based on a detailed database of traditional plant uses. Hot-spots of GF species diversity were found in the southwest and southeast of BFA. GFs were the third most species-rich habitat and by far the most species-rich of all azonal habitats in BFA. About 15 % (307 species) of all plant species known to BFA occured in GFs, although they only covered a minor area (up to 1 %) of the total country area. The flora of GFs differed taxonomically and functionally from the dominating flora of BFA. The importance of phanerophytes and lianas, especially of the families Rubiaceae, Apocynaceae, Acanthaceae, Moraceae and Vitaceae was increased. In contrast, the species number of therophytes, especially of the families Poaceae, Cyperaceae, and Asteraceae was reduced in GFs. The distinct composition of the GF flora was also reflected in traditional use patterns. The proportion of species with a known traditional use was higher in GFs than in the total national flora. This was the case for the use in traditional medicine (55 % vs. 36 %) in particular, but also for construction, tool production, firewood and religious purposes. The results showed the particularity of GFs, differing from the dominating vegetation of BFA and stressed their importance as unique habitat for a large number of species. The taxonomic and functional composition of GFs underlined their role in extending the distribution range of forest species northwards into drier and more seasonal parts of the West African climate gradient. These unique features of GFs and their demonstrated importance for traditional plant use by local human populations

stressed their importance in conservation strategies. Furthermore, the history of species recordings in BFA revealed an increase in the discovery of GF specific species in the last decade, suggesting, that GFs are still understudied and that further research might reveal species new to BFA.

II) In the last two million years (the Pleistocene), wet-dry cycles associated with glacial and interglacial periods have potentially caused waves of forest expansion and retraction in West Africa. During the last cycle, the 'Last Glacial Maximum' (LGM, 19,000 years before present (BP)) is considered the driest phase, and the mid-Holocene (ca 5,000 years BP) the moisture optimum in West Africa. These extremes supposedly caused a minimum and maximum of forest extent and GF species distribution in West Africa, respectively. The response of GF species to these events might inform about expected vegetation changes during the current climate change. In section 3.2 of this thesis an unprecedented number of occurrence records was used to model the distribution of 20 characteristic GF species throughout West Africa at four time slices: the LGM, the mid-Holocene, present day and the year 2085. Furthermore, the distribution data were used for a preliminary conservation assessment of the study species orientated on IUCN criterion B. There was a significant variance in species response to climate conditions. The most significant variables to predict the distribution of GF species in West Africa were 'mean annual temperature', 'mean annual precipitation' and 'precipitation of the driest quarter', the 'topographic wetness index' and the 'minimum distance to the nearest major river'. Overall trends showed a much reduced potential distribution of GFs during the LGM with only a few suitable areas remaining in southern West Africa, outside the borders of what is BFA today. The area suitable for GFs in West Africa increased continuously since then, with a comparable extent of suitable habitats in the mid-Holocene and today, and a potential increase in suitable area under future climate conditions. In BFA virtually no suitable habitats for GFs were found during the LGM. For all other time slices suitable habitats for most of the studied species were closely related to river occurrence. Most of the study species showed wide distribution ranges (large 'extent of occurrence') but occupied only relative few areas within this range (small 'area of occupancy') leading to a classification of most species as "vulnerable" or "endangered". The results stressed the sensibility of GFs in West Africa to climate changes. The restriction of GFs to southern West Africa during the LGM, and in particular the lack of refugia in the latitudes of current day BFA suggested a rapid recolonization of the area by forest species from the south since then. The conservation assessment stressed the vulnerability of GF species, despite their general wide distribution ranges due to the relatively low number of habitats within the distribution range actually occupied.

III) West Africa is governed by a climatic gradient with a relatively homogeneous increase of precipitation and a decrease in precipitation seasonality and temperature from north to south. This gradient leads to "banded" regional vegetation changing from desert and shrubland over savannas and woodlands to rainforest. During Pleistocene climate changes these bands potentially oscillated north- and southwards, and GFs have been proposed as refugia and dispersal corridors for forest species. In sections 3.3, 3.4 and 3.5 the genetic population structure of four characteristic GF species across BFA was studied to test this hypothesis: *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Paullinia pinnata* and *Pterocarpus santalinoides* differ in ecology (i.e. dispersal mode), range size and the dependence on GFs as habitat. Based on 245 plant tissue samples from study sites across BFA, the genetic population structure of all four species was analysed using 'amplified fragment-length polymorphisms' (AFLPs). The genetic data was used to test the influence of the three major river basins, 24 environmental variables and geographic distance on the genetic population structure. There were distinct genetic populations for all study species within the borders of BFA, but with significant admixture. There was no correlation between population structure and river basins in any of the four species, irrespective of dispersal mode and current day range size. Instead, population structure was correlated with environmental factors in all species. The importance of different environmental factors varied with species, but 'mean annual temperature' and 'maximum temperature of the warmest month' had significant influence in three out of four species. A phylogeographic analysis using species-tree diffusion models in BEAST revealed a directional colonization of BFA from the south and distinct east-west splits in all four study species. Furthermore, the signature of recently increased dispersal was detected in all species. The results did not support the hypothesis of GFs as refugia or dispersal corridors in Burkina Faso, but the observed genetic structure rather suggested different ecotypes, possibly related to temperature.

In conclusion, the results presented in this thesis show an assessment of GFs in BFA and their historical biogeography in West Africa. Albeit, only covering a small fraction of the country area, GFs contribute significantly to the national phytodiversity. Due to their particular composition and structure GFs are of particular importance as habitat for plant and potentially, animal species, otherwise absent to the country. Additionally, they are of particular importance to local human populations. The results presented do not support the hypothesis that GFs served as refugia for forest species in what today is BFA or in similar latitudes across West Africa during the Pleistocene climate fluctuations. Rather, most forest species potentially recolonized this area from climatically more stable regional refugia in the south of West Africa in the last 19,000 years since the LGM. This recolonization might have been independent from major river basins following climatic conditions. Despite their often large distribution range, many GF species can be considered as endangered. The concentration of nationally endangered species in GFs and the high biodiversity of these areas make GFs an important and promising target for conservation.

Deutsche Zusammenfassung

1. Fragestellung

Galerie- oder Auenwälder (GW) sind floristisch und strukturell charakteristische Vegetationsformen, die, oftmals in schmalen Streifen, entlang von Flüssen oder Flussbetten auftreten. Sie sind ein nahezu allgegenwärtiges Element der westafrikanischen Savanne, in das viele Arten der Regenwälder der Guinea-Zone in die Sudan- und sogar Sahel-Zone ausstrahlen. Die GW in der westafrikanischen Savanne unterscheiden sich deutlich von der umgebenden Vegetation und beherbergen eine einzigartige und charakteristische Flora. Auf Grund ihrer isolierten Lage und Abhängigkeit von Flüssen sind diese hochdiversen Ökosysteme besonders bedroht: zum einen durch die intensive menschliche Nutzung, zum anderen durch den erwarteten globalen Klimawandel im 21. Jahrhundert. Trotz ihrer faszinierenden Artenvielfalt und der zunehmenden Bedrohung ist über die Ökologie und Vegetationsdynamik von GW in Westafrika wenig bekannt. Zahlreiche Neufunde von Arten aus den GW belegen, dass diese auch in ihrer Artendiversität noch relativ wenig erforscht sind; auch wenn immer detailliertere Klimaprognosen für Westafrika vorliegen, sind die Folgen von Klimaveränderungen auf GW und die Widerstandskraft von GW gegen solche Veränderungen noch weitgehend unbekannt. In der vorliegenden Arbeit werden floristische, ökologische und genetische Daten kombiniert, um Artenvielfalt, Biogeographie und Erhaltungszustand von GW in Burkina Faso (BFA) besser verstehen zu können. Aufgrund der Lage von BFA, das sich von der Südsudan-Zone bis zur Sahel-Zone erstreckt, und der gürtelförmigen Anordnung der Klima- und Vegetationszonen in Westafrika haben die Ergebnisse Modellcharakter für das gesamte Westafrika.

2. Datengrundlage

Als Grundlage der Untersuchung der Artendiversität und der Arealmodellierung wurde auf der Basis der Literatur, von Expertenwissen und eigenen Beobachtungen im Gelände eine Liste der Galeriewaldarten von Burkina Faso erstellt. Diese umfasst 307 Blütenpflanzen-Arten. Für diese Arten wurde eine umfassende Verbreitungsdatenbank für BFA und angrenzende Gebiete erstellt. Neben der Auswertung der Literatur und der GBIF-Datenbank lieferten die Herbardatenbanken des Herbarium Senckenbergianum in Frankfurt (FR) und des Herbars in Ouagadougou (OUA) sowie die Daten von Feldarbeit dazu die Datengrundlage. Insgesamt standen für die GW-Arten 1658 georeferenzierte Fundpunkte zur Verfügung. Das Material für die populationsgenetischen Untersuchungen wurde in einer vierwöchigen Geländekampagne 2009 gesammelt und durch weitere Aufsammlungen von Dr. Thomas Janssen und Dr. Marco Schmidt aus dem Jahre 2008 und von Prof. Dr. Stefan Porembski aus dem Jahr 2010 ergänzt. Als zu untersuchende Arten wurden vier weitverbreitete GW-Arten ausgewählt, die sich im Verbreitungsmodus und ihrer Abhängigkeit von unmittelbarer Nähe zum Wasser unterschieden. In der Reihenfolge zunehmender Abhängigkeit von der Nähe zum Fluss waren dies *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Paullinia pinnata* und *Pterocarpus santalinoides*. Insgesamt wurden 245 Proben gesammelt, mit Silicagel getrocknet, mit Herbarbelegen dokumentiert und die jeweiligen Fundorte georeferenziert. Die Untersuchung der genetischen Struktur erfolgte mit der 'amplified fragment-length polymorphism-Methode' (AFLPs). Für die Arealmodellierung wurden 20 weitverbreitete, in ihrem Vorkommen gut dokumentierte GW-Arten ausgewählt. Für die Gegenwart wurden Klimadaten von AFRICLIM (Platts *et al.* 2014) genutzt. Für die Zukunft wurde ein 'ensemble model' von AFRICLIM verwendet, das auf dem 'RCP 4.5 scenario' basiert. Die Paläo-Klimadaten wurden von BIOCLIM (Hijmans *et al.* 2005) heruntergeladen und basieren auf dem Community Climate System Model (CCSM4). Weitere wichtige Umweltdaten lieferten der 'topographic wetness index' und die Informationen über die 'minimum distance to the nearest major river". Die naturschutzfachliche Bewertung der 20 häufigen GW-Arten nach IUCN Kriterien erfolgte schliesslich mit Hilfe des Programms GEOCAT (Bachman *et al.* 2011) der Royal Botanic Gardens, Kew.

3. Artenvielfalt und Nutzung

Aufbauend auf die floristischen und habitatbezogenen Daten wurden in Kapitel 3.1 dieser Arbeit die Verteilungsmuster des Artenreichtums untersucht und basierend auf diesen Daten die Artenvielfalt, die taxonomische Zusammensetzung und funktionelle Diversität von GW auf nationaler Ebene untersucht und mit der Gesamtflora verglichen. Des Weiteren wurde die Relevanz von GW für die traditionelle Pflanzennutzung durch die lokale Bevölkerung beleuchtet. GW sind das drittartenreichste Habitat in Burkina Faso und das mit Abstand artenreichste der untersuchten azonalen Habitattypen. Nahezu 15 % (ca. 307 Arten) aller aus BFA bekannten Pflanzenarten kamen in GW vor, obwohl GW maximal 1 % der Landesfläche ausmachen. Die Flora der GW unterschied sich deutlich in taxonomischer und funktioneller Zusammensetzung von der Gesamtflora von BFA. Die Zahl der Phanerophyten und Lianen, insbesondere aus den Familien Rubiaceae, Apocynaceae, Acanthaceae, Moraceae und Vitaceae war in GW deutlich höher. Im Gegensatz dazu war die Häufigkeit von

Therophyten, insbesondere aus den Familien Poaceae, Cyperaceae und Asteraceae, in GW stark reduziert. Hemikryptophyten und Geophyten waren in GW etwas weniger divers. Eine Analyse der Literatur und der Aufsammlungen von Pflanzenarten in BFA zeigte, dass die Anzahl der Galeriewaldspezialisten, die im letzten Jahrzehnt erstmals für BFA beschrieben wurden, besonders hoch ist. Der Anteil von Arten mit einer bekannten traditionellen Nutzung war deutlich höher in der GW-Flora als in der gesamten Flora von BFA. Dies zeigte sich besonders für die Nutzung in traditioneller Medizin (55 % gegenüber 36 %) aber ebenfalls in der Nutzung als Baumaterialien, Werkzeugmaterial, Feuerholz und für religiöse Zwecke. Die Ergebnisse unterstreichen die wichtige Rolle von Galeriewäldern als einzigartiges Habitat für seltene Tier- und Pflanzenarten, insbesondere als wichtige nördliche Erweiterung des Lebensraums für Waldarten in ansonsten zu trockenen und von saisonalen Niederschlägen geprägten Bereichen des regionalen Klimagradienten. Die hier gezeigten Besonderheiten von Galeriewäldern und ihre demonstrierte herausragende Rolle für die lokale Bevölkerung zeigt die Wichtigkeit der Galeriewälder für die nationale Flora und für Naturschutzbemühungen.

4. Arealmodellierung und Arealentwicklung seit dem Last Glacial Maximum (LGM)

Die klimatischen Schwankungen im Pleistozän (Eis- und Warmzeiten) haben in Westafrika hauptsächlich zu abwechselnden Trocken- und Feuchtperioden geführt. Das "Last Glacial Maximum" (LGM, ca. 19.000 Jahre BP (before present)) als Höhepunkt einer letzten Trockenphase und das mittlere Holozän (ca. 5.000 Jahre BP) als Höhepunkt der letzten Feuchtperiode markieren die letzten Extrempunkte, die mutmaßlich zu einer minimalen bzw. maximalen Waldausdehnung und damit verbunden zu minimalen bzw. maximalen Verbreitungsarealen von Waldarten geführt haben. Ein besseres Verständnis der Vegetationsausbreitung zum Zeitpunkt dieser beiden Extreme kann helfen, die zu erwartenden Vegetationsverschiebungen durch den globalen Klimawandel des 21. Jahrhunderts zu verstehen. Kapitel 3.2 dieser Arbeit nutzt die zusammengestellte, umfangreiche Datenbank von georeferenzierten Verbreitungspunkten zur Modellierung der geographischen Verbreitung von 20 Galeriewaldarten in Westafrika während LGM, mittlerem Holozän sowie in der Gegenwart und Zukunft (2085). Des Weiteren wurden die Verbreitungsinformation für eine naturschutzfachliche Bewertung der 20 Untersuchungsarten nach IUCN Kriterium B benutzt. Die informativsten Umweltfaktoren zur Modellierung der Artverbreitung waren 'mittlere Jahrestemperatur', 'mittlerer Jahresniederschlag', 'Niederschlag im trockensten Quartal', 'topographischer Feuchtigkeitsindex (TWI)' sowie die 'geringste geographische Entfernung zum nächsten Fluss'. Wie erwartet war die für die Untersuchungsarten geeignete Fläche während des LGM deutlich kleiner als im mittleren Holozän und der Gegenwart. Während des LGM waren nur einige Gebiete im Süden Westafrikas (also ausserhalb der heutigen Grenzen BFAs), in der heutigen Guinea-Vegetationszone, für die Untersuchungsarten geeignet. Seit dieser Zeit hat die Fläche der GW kontinuierlich zugenommen, mit einer vergleichbaren Ausbreitung zwischen dem mittleren Holozän und der Gegenwart, und einer potentiellen Vergrößerung geeigneter Habitate im 21. Jahrhundert. Während des LGM gab es keine nennenswerten Bereiche mit geeigneten Habitatbedingungen für die untersuchen Arten in Gebiet von BFA. Zu den drei anderen untersuchten Zeitpunkten waren geeignete Habitate in weiten Teilen des untersuchten Gebiets an die Nähe zu größeren Flüssen gebunden. Die meisten der untersuchten Arten hatten ein ausgedehntes Verbreitungsareal (ausgedehnter 'extent of occurrence') kamen allerdings nur in wenigen Teilen dieses Gebiets tatsächlich vor (kleine 'area of occupancy'). Diese geringe tatsächliche Verbreitung führte zu der Einstufung der meisten Arten als gefährdet. Die gezeigten Ergebnisse unterstreichen die Anfälligkeit von Galeriewaldarten gegenüber klimatischen Veränderungen. Die stark eingeschränkte Verbreitung geeigneter Habitate während des LGM deutet auf das Fehlen von lokalen Refugien in BFA und stattdessen auf eine Wiederbesiedlung aus regionalen Refugien im südlichen Westafrika innerhalb der letzten 16.000 Jahre hin. Wie erwartet korreliert die Zunahme von geeignetem Habitat mit feuchterem Klima. Die projizierte Zunahme von geeigneten Habitaten im 21. Jahrhundert war überraschend. Möglicherweise gibt es hier einen Zusammenhang mit temperatursensitiven Ökotypen der Untersuchungsarten (Kapitel 3.2), aber weitere Untersuchungen dieses Phänomens sind dringend geboten.

5. Genetische Populationsstruktur

Das Klima Westafrikas wird von einer relativ homogenen Zunahme von Niederschlag zusammen mit einer Abnahme von Niederschlagssaisonalität und Temperatur von Norden nach Süden geprägt. Dieser regionale Klimagradient führt zu einer "bandartigen" Anordnung von Vegetationsformen, von Wüste, Grasland und lichten, trockenheitsliebenden Buschlandschaften zu mehr oder weniger dichter Savanne und letztendlich Regenwald an der Küste. Während der pleistozänen Klimaschwankungen wanderten diese Vegetationszonen vermutlich süd- und nordwärts und GW spielten möglicherweise eine entscheidende Rolle als Refugien und Verbreitungskorridore für waldlebende Tier- und Pflanzenarten. Kapitel 3.3 dieser Arbeit untersucht die genetische Populationsstruktur von vier typischerweise in GW vorkommenden Pflanzenarten in BFA. *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Paullinia pinnata* und *Pterocarpus santalinoides* sind charakteristische Elemente in den GW Westafrikas; aber sie unterscheiden sich in Ökologie (Verbreitungsmodus), Größe des Verbreitungsgebietes und im Grad der Abhängigkeit von Galeriewäldern. Basierend auf Proben von insgesamt 245 Individuen aus allen Teilen des Landes wurde die genetische Populationsstruktur mit Hilfe von 'amplified fragment-length polymorphisms' (AFLPs) untersucht. Diese Daten wurden dann benutzt, um den Einfluss von den drei maßgeblichen Flusssystemen, 24 verschiedenen Umweltfaktoren sowie der geographischen Entfernung auf die genetische Populationsstruktur zu testen. Alle untersuchten Arten wiesen eine klare Populationsstruktur auf, allerdings mit signifikanter geographischer Vermischung dieser Populationen. Bei keiner der untersuchten Arten bestand ein Zusammenhang zwischen Populationsstruktur und Flußsystemen, unabhängig vom Verbreitungsmodus. Stattdessen gab es eine Korrelation zwischen Populationsstruktur und Umweltfaktoren bei allen Arten. Der Einfluss verschiedener Faktoren war von Art zu Art unterschiedlich, aber die Jahresdurchschnittstemperatur und die 'maximale Temperatur im wärmsten Monat' hatten einen signifikanten Einfluss in drei der vier Untersuchungsarten. Zusätzlich zeigte eine phylogeographische Analyse (species-tree diffusion model) mit dem Programm BEAST eine Kolonisation BFA von Süden und eine klare Ost-West Trennung der Populationen in allen vier Arten. Dieses Muster wird von einer ungerichteten Ausbreitung in alle Richtungen in neuerer Zeit abgelöst. Die vorgelegten Ergebnisse liefern keine Unterstützung für die Hypothese, dass die GW der großen Flußsysteme als Refugien oder Verbreitungskorridore für waldlebende Arten dienten. Dagegen unterstützen sie die Besiedelung von BFA mit Waldarten von Süden her und damit die Hypothese der Vegetationsoszillation. Weiterhin deutet die genetische Struktur eine wichtige Rolle von Umweltfaktoren an, die möglicherweise auf verschiedene Ökotypen innerhalb der Arten hinweisen.

6. Entstehung der heutigen Populationsstruktur

Die vorliegende Arbeit zeigt deutlich, dass keine Verbreitung der vier untersuchten GW-Arten (*Anogeissus leiocarpa, Diospyros mespiliformis, Paullinia pinnata, Pterocarpus santalinoides*) entlang von Flüssen stattgefunden hat. Das 'species-tree diffusion model' zeigt, dass bei allen vier Arten zuerst eine Teilung in eine westliche und eine östliche Population stattfand. Danach folgte eine weitere Verbreitung in nord-südlicher Richtung. Je mehr Zeit verstrich, desto zufälliger wurde die Verbreitung bis das ursprüngliche Verbreitungsmuster völlig überdeckt war.

7. Schutz und Erhaltung von Galeriewäldern

Die Ergebnisse dieser Arbeit zeigen, welch diverse und einzigartige Habitate Galeriewälder sind, besonders bezogen auf ihre Artenzusammensetzung, ihre Lebensformen, und wie sie überproportional zur nationalen Flora Burkina Fasos beitragen. Außerdem werden GW intensiv von der lokalen Bevölkerung für vielfältige Zwecke genutzt, z. B. medizinisch und religiös, als menschliche Nahrungsquelle und als Quelle für Tierfutter. Dadurch sind die GW in BFA einem starken Nutzungsdruck ausgesetzt. Die verschiedenen Ansätze zum Verständnis der historischen und gegenwärtigen Biogeografie von GW in dieser Arbeit können hoffentlich dazu beitragen, die Veränderungen der Biodiversität in GW zu dokumentieren und somit den Schutz von GW zu verbessern. Alle hier untersuchten Arten kommen in weiten Teilen Westafrikas vor, was sie generell vor dem Aussterben schützt. In BFA ist das Vorkommen der meisten Arten jedoch auf den Süden des Landes beschränkt. Dadurch sind viele der untersuchten Arten lokal vom Aussterben bedroht, wenn ihr Lebensraum für die Landnutzung durch den Menschen zerstört wird. Die Ergebnisse dieser Arbeit zeigen, dass bei einem moderaten Klimawandel die Beschränkung der Landnutzung durch den Menschen ein wichtiger Faktor zum Erhalt von GW in BFA ist.

Zusammenfassend zeigen die Ergebnisse erstmalig eine umfassende Einschätzung der Vegetation von GW in Westafrika. Trotz ihrer verhältnismäßig geringen Fläche tragen GW maßgeblich zur Phytodiversität BFA bei und sind auf Grund ihrer Einzigartigkeit gegenüber der umgebenden Vegetation von besonderer Bedeutung, sowohl als Habitat für Pflanzen als auch als Lebensgrundlage für die lokale Bevölkerung. Während der pleistozänen Klimaschwankungen waren die klimatischen Bedingungen auf der Fläche des heutigen BFA weitestgehend ungeeignet für Galeriewaldvegetation. Ein Großteil der Waldarten haben dieses Gebiet (und Gebiete ähnlicher geographischer Breite) vermutlich erst seit dem LGM aus Refugien im südlichen Westafrika wiederbesiedelt. Diese Ausbreitung erfolgte relativ unabhängig von den großen Flußsystemen entlang des Klimagradienten. Trotz der weiten regionalen Verbreitung vieler Galeriewaldarten sind diese akut gefährdet. Die Konzentration vieler landesweit bedrohter Arten in GW und deren hohe Biodiversität machen GW zu einem wichtigen und erfolgsversprechenden Ziel für Naturschutzbemühungen.

1

Gallery Forests in West Africa – an Introduction

Climate change is a major challenge for humanity in the 21st century. Although the exact future climate conditions remain uncertain, there is a consensus that global temperature will increase, rainfall patterns will change and that the frequency of extreme events, such as droughts, will increase (IPCC 2014). These changes will critically influence all life on earth, including humans. One of the largest impacts of climate change on humans might result from vegetation changes, with severe impacts on agriculture, ecosystem services and biodiversity.

The adverse effects of climate change will in particular effect rural areas of developing countries where dependencies on the environment often are strong, direct and local, and the resources to mitigate adverse effects are limited. West Africa, bordered by the Sahara in the north, the Atlantic Ocean in the west and south, and the countries of Chad and Cameroon in the east (fig. 1) is a developing region with projected severe changes in climate and vegetation. West Africa comprises 15 mainland countries and in total covers about 6.1 million km^2 equal to 20 % of the African continent.

Today the average gross national income per capita is 1,160 US Dollars compared to 44,031 in Western Europe (United Nations 2015), which is the second lowest regional value globally. While modern life and megacities exist, large parts of the population still live under rural and simple conditions and directly depend on local natural products for food, medicine and daily life (Guinko 1984, Beiersmann *et al.* 2007, Central Intelligence Agency 2015). A strong increase in human population and a related intensification in land-use are expected in the next 50 years. This increase in population and the related increasing demand for food and other ecosystem services goes along with projected changes in precipitation and temperature, potentially leading to large scale changes in vegetation cover in almost all parts of West Africa. Desertification, forest retraction and loss of crop land and crop yields are expected consequences (Berg *et al.* 2013, Roudier *et al.* 2011, Gonzalez 2001, Wittig *et al.* 2007).

The current climate change is unique in its causes, speed and impact on human population, but the climate in West Africa has fluctuated in comparable magnitude in the recent past, during the geological epochs Pleistocene and Holocene (approximately the last 2.6 million years). Information on climate, vegetation and flora during these past fluctuations is today available from different sources, such as paleoclimate and -vegetation reconstructions, palaeontology and molecular biology.

Fig. 1: Political map of West Africa (without taking the British overseas territory of Saint Helena into account) as referred to in this study. The mainland region comprises 15 countries, most of them with a gross national product in the lowest 20 % globally according to the United Nations Statistics Division 2 (United Nations 2015).

This opens the unique opportunity to use these past events to understand the processes and drivers acting on the vegetation under current climate change and to develop possible scenarios and conservation strategies for the future.

Climate change has a strong influence on regional biodiversity and community composition, potentially affecting all facets of diversity, including species richness, functional diversity and genetic diversity. Numerous studies have shown the influence of climate change on species ranges across taxonomic groups and its potential to cause range shifts and extinctions (Brook *et al.* 2008, Keith *et al.* 2008, Midgley *et al.* 2002, Heubes *et al.* 2013, Thuiller *et al.* 2005, Thuiller *et al.* 2006, Thomas *et al.* 2004, McClean *et al.* 2005). Through these processes biota of many ecosystems, biomes and habitats will change. While these changes can lead to local increases or decreases in diversity, especially areas with fragmented or azonal habitats, such as gallery forests (GFs) are in danger of substantial diversity loss due to extinction.

Azonal habitats significantly differ in environmental conditions from their surroundings, leading to peculiar, often very distinct communities. Global examples for azonal habitats are GFs, open savanna areas within the Amazon rainforest, isolated high mountains e.g. the Tepui table mountains in South America, and the vegetation of rocky outcrops or cliff overhangs (Mucina *et al.* 2006, Anderson 1981, Gröger & Huber 2007, Sambaré *et al.* 2011, Schmidt *et al.* 2013, Sieben *et al.* 2009, Müller *et al.* 2012). Often, these azonal habitats are characterized by high diversity and high levels of endemism (Porembski *et al.* 1994, Müller *et al.* 2012).

The West African vegetation is dominated by the large African savannah belt. In this relatively homogenous (Zizka *et al.* 2015b) and gradually changing vegetation typical azonal habitats include: GFs (increased water-availability and protection from fire, Guinko 1984, Sambaré *et al.* 2011), "inselbergs" (isolated rocky outcrops, associated with special soil conditions and protection from fire Müller 2008, Sarthou 2002, Porembski *et al.* 1994, Porembski & Barthlott 1992, Bornhardt 1900), "bowé" (lateric crusts, shallow soils and mechanic stress, Zwarg *et al.* 2012) and termite mounts (higher nutrient and water availability, different soil texture and protection from fire, Kirchmair *et al.* 2012, Jones *et al.* 1997, Arshad 1982, Dangerfield *et al.* 1998, Konaté *et al.* 1999, Wood 1988). Of these examples, GFs play a particularly important role due to their abundance, high biodiversity, their linear rather than isolated structure and their importance for the human population.

GFs are a characteristic element of the West African vegetation and mostly occur as narrow stripes along rivers or riverbeds in regions otherwise to dry for forest. These forests harbour species otherwise mainly confined to the moisture forest regions in the Sudanian and Guinean zones in southern West Africa, extending the ranges of these species northwards considerably, and additionally, are a habitat for a set of specialist species. Their particular flora make GFs an important element of regional diversity and an important source of economically important plant species for local human communities. As for all azonal habitats, GFs are particularly sensitive to climate changes. Their isolated nature limits the possibility for species to track climate change by migration or dispersal. In West Africa the regional climate gradient from dry and seasonal conditions in the north to high rainfall in the south leads to characteristic latitudinal vegetation bands. Past climate changes have been related to north-south oscillations of these bands. More specifically, moist-dry phases in the Pleistocene can be related with northward expansion and southwards retraction of forest, respectively. Given these patterns, GFs might have played a key role as refugia for forest species during dry cycles and as dispersal corridors and source of expansion during wetter periods.

West African GFs are understudied habitats. Only few studies, mainly of floristic and phytosociological nature, and of local scale exist. A large-scale synthesis of vegetation history and diversity patterns is, to my knowledge, missing. Even the number of plant species in these habitats and, in particular, their response to climate change remains unclear. This lack of knowledge severely hampers conservation efforts, which is particularly problematic in those areas where predicted strong climate changes fall together with strong predicted increases in population, land-use intensification and a low standard of living.

In this thesis I use the country of Burkina Faso as model to investigate the diversity, plant use, biogeography and the effects of climate change on West African GFs.

1.1 Gallery Forests

Gallery forests (GFs), also named riverine or riparian forests, are characteristic forest formations along rivers, lakes, watercourses or seasonally dry waterbeds. GFs are a common vegetation form around the globe and occur in many different ecosystems such as temperate forests, savannas and shrublands. Often, GFs differ significantly in structure and floristic composition from the surrounding vegetation (Guinko 1984, Sambaré *et al.* 2011, Veneklaas *et al.* 2005, Ceperley *et al.* 2010, Koponen *et al.* 2004, Maingi & Marsh 2006, Müller *et al.* 2012) and are often significantly more diverse (Pither & Kellman 2002, Suzuki *et al.* 2002, Natta 2003, Da 2010, Koponen *et al.* 2004, Maingi & Marsh 2006). The increased diversity has been associated with higher water availability, but also to recurrent disturbance or high microhabitat diversity. The individual importance of each of these factors might differ among biomes. For example, GFs within temperate forest are mainly caused by disturbance, flooding duration and soil anaerobic conditions whereas in savannas, protections from fire, increased water availability and potentially increased soil fertility supposedly are more important (Zizka *et al.* 2017, Scheiter & Higgins 2009, Sieben *et al.* 2009, Mucina *et al.* 2006, Veneklaas *et al.* 2005, Ceperley *et al.* 2010).

In BFA, Guinko (1984) defined GFs as "toutes les formations forestières tributaries de la presence d'un cours d'eau situé à proximité" ["All forested formations dependent on a watercourse and situated in its closed proximity"] (p. 185). The same author also notes the importance of GFs for extending the range of forests species northwards, such as *Anogeissus leiocarp*a and *Diospyros mespiliformis*, common in the south of BFA. GFs can occur along permanent rivers, but also along seasonal rivers that dry out during the dry season. In the more mesic southern parts of BFA, GFs often consist of two different zones: the so called "cordon ripicole", constituted by the vegetation immediately adjacent to the river, directly depending on the presence of running water and adapted to recurring and long-term flooding; and the GFs *sensu stricto* forming a band of deciduous or semi-deciduous forest along the watercourse, adapted to sporadic flooding but also intrusion of savanna fires. In BFA most GFs burn sporadically, with exception of those situated closely to the largest permanent watercourses.

The physiognomy of GFs is, as for all vegetation formations in Burkina Faso, changing following the climatic gradient. In general, the extent of the forests increases from north to south. While GFs in the north are restricted to few meters or sometimes a few individual trees, GFs in the south can extent several hundred meters away from the watercourse into the savanna (fig. 2). Many of the GFs of the northern Sahel barely merit the name forest and are often only constituted of few medium to small-sized woody individuals of a few species. In contrast, the wide GFs in the south of the country resemble the Guineo-Congolian forests, with a closed, high canopy, large emergent trees (up to 40 m) and a dense understory (but lianas and epiphytes are mostly absent). Figure 3 visualises this physiognomic gradient from the sparse northern GFs (fig. 3A) to the dense vegetation in the south (fig. 3H). While the distinction between the "cordon ripicole" and the GFs *sensu stricto* is relatively clear in the south, it blurs more and more towards the north.

Sambaré *et al.* (2011) found a total of 196 species from 139 genera and 51 families in the GFs of BFA, with species richness increasing from north to south. The flora of GFs in a given climatic zone consists usually of few specific GF specialists together with forest species of the neighbouring moister zone from the south. Generally, from north to south, forest elements shift from the watercourse more and more towards the GF borders, and savanna elements enter the GFs, leading to an increase in width and a reduction in border "fuzziness" from north to south (Guinko 1984). The climate gradient also leads to a continuous decrease of Sudano-Sambesian and increase of Guineo-Congolian elements in the GFs. Typical species of GFs in BFA are *Kigelia africana*, *Elaeis guineensis*, *Carapa procera* and *Berlinia* *grandiflora* (Thiombiano *et al.* 2013), but the GFs in the four vegetational zones differ considerably. Following Guinko (1984):

The GFs of the **Sahel** and **sub-Sahel** are very different from the other zones, sometimes consisting only of few woody individuals, often very compact and densely armed with spines (fig. 3A+B). In the southern parts of the sub-Sahel single emergent individuals can reach up to 35 m, but mostly plant height is limited to 7-10 meters or even less. The most dominant species is *Anogeissus leiocarpa*; other characteristic species include *Acacia ataxantha*, *Acacia seyal*, *Ziziphus mucronata Combretum micranthum*, *Balanites aegyptiaca, Diospyros mespiliformis, Mitragyna inermis,* and *Piliostigma reticulatum.* The most important plant families are Fabaceae, Combretaceae, Rubiaceae, and Ebenaceae. The herb layer mostly consists of different species of Poaceae. Phanerophytes are dominant and the flora is dominated by Sudano-Sambesian elements, with no Guineo-Congolian species present.

The GFs of the **North Sudanian zone** mostly occur around seasonal water courses. The "cordon ripicole" is less pronounced and sometimes indistinguishable. The GFs *sensu stricto* is relatively homogeneous throughout the zone, resembling lose canopy forests ("forêts claires") or densely covered savannas ("savanes boisées") (fig. 3C-E). Emergent individuals, mostly of *Khaya senegalensis* and *Daniellia oliveri* reach up to 35 m. Characteristic species are *Pterocarpus santalinoides*, *M. inermis*, *D. mespiliformis*, *D. oliveri* and *A. leiocarpa*. The most important plant families are Fabaceae, Combretaceae, Rubiaceae and Ebenaceae. The borders of the GFs are often fuzzy and sometimes not clearly distinguishable. Phanerophytes dominate, but less than in the GFs of the South Sudanian, and the fraction of Guineo-Congolian elements only reaches a mere 3 %.

The GFs of the **South Sudanian zone** are the densest GF formations in BFA and form compact, relatively wide, semi-deciduous forests (fig. 3F-H). Dominant species are *Antiaris africana*, *Chlorophora excelsa*, *K. senegalensis* and *Cola cordifolia*. These forests often have a distinct "cordon ripicole", characterized by woody evergreen species such as *Cola laurifolia* and *Morelia senegalensis*, and containing some characteristic herbaceous species including *Chloris robusta*, *Herderia truneata*, *Oxystelma boronouense* and *Cyperus maculatus*. The GFs *sensu stricto* of the South Sudanian are variable but vastly dominated by phanerophytes with characteristic species including: *C. cordifolia*, *Manilkara multinervis*, *K. senegalensis*, *D. oliveri, B. grandiflora, Vitex chrysocarpa, Syzygium guineense, Dialium guineense, D. mespili-*

formis and *Borassus aethiopium*. The most important plant families are Fabaceae, Sterculiaceae, Lamiaceae, Rubiaceae and Meliaceae. Guinko (1984) found a composition of 67 % Sudano-Sambesian, 16 % Guinean-Congolean and 17 % widespread species in the GFs of this zone.

West African GFs differ significantly from the surrounding vegetation. They are unique habitats and increase the phytodiversity of BFA offering a habitat for species that otherwise would not occur in the country, by i) extending the distribution range of Sudano-Congolian species northwards, ii) harbouring a set of local habitat specialists (Naiman *et al.* 1993) and iii) providing an major habitat for 70 % of the woody species known to BFA (Sambaré *et al.* 2011). The same is supposedly true for animal species that use GFs as habitat. The particular GF flora, with rare species and a high proportion of woody elements also leads to a high economic and social value for local human communities (Natta 2003, Ceperley *et al.* 2010, Naiman & Decamps 1997). Unfortunately, GFs in Burkina Faso face severe threats and have been classified as endangered ecosystems (Sambaré *et al.* 2011). In particular land-use changes with clearing of the forest for agriculture, increased pressure by livestock farming, but also changes in water level due to dam or hydroelectric power plant constructions pose a severe challenge for GF ecosystems in the country (Sambaré *et al.* 2011) and make concentrated conservation efforts necessary to sustain these unique ecosystems.

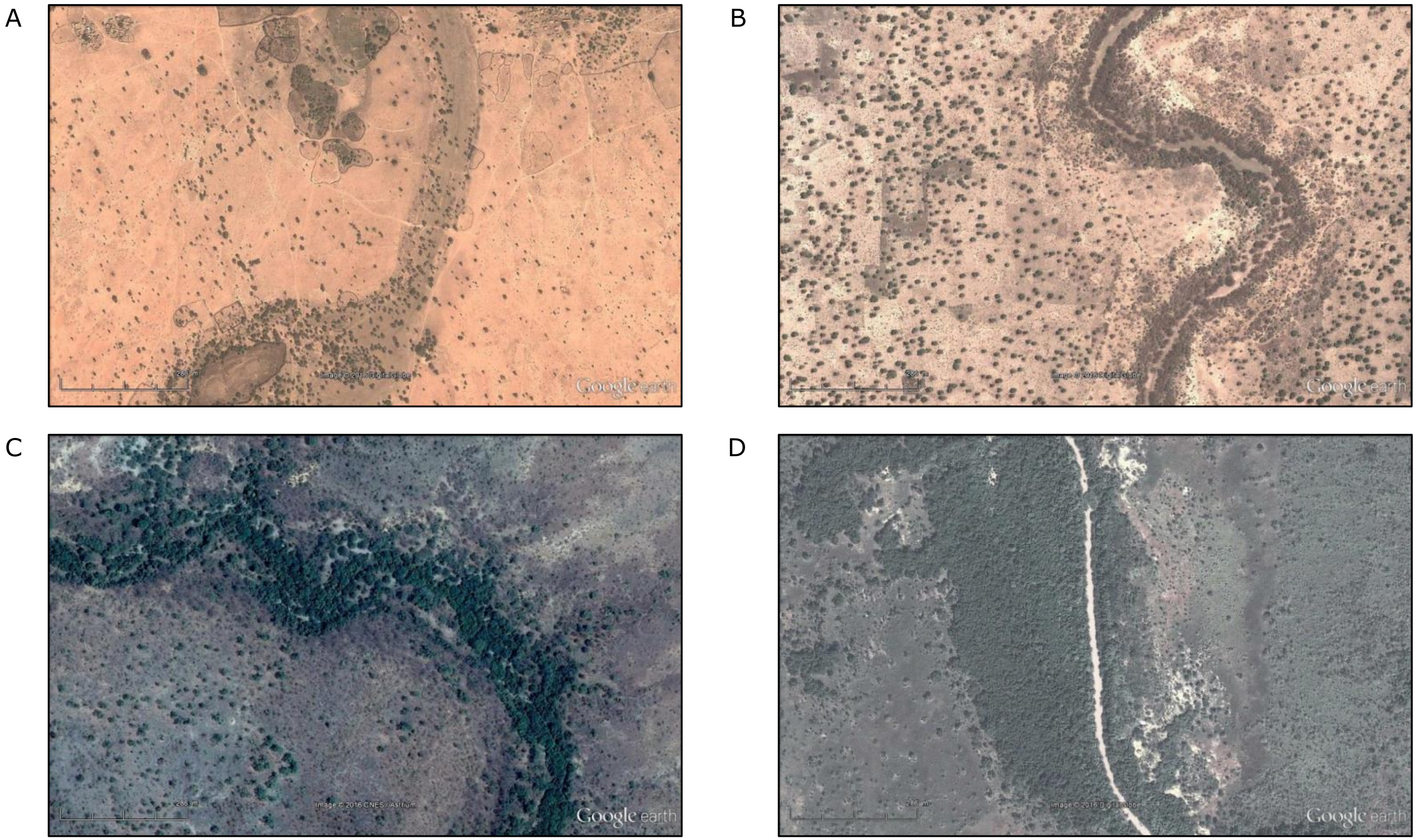

Fig. 2: Satellite images of gallery forests in Burkina Faso, from north to south. Subfigure letters refer to the letters and geographic position in figure 6B. A) close to Djibo; B) close to Dedougou; C) close to Leo; D) close to Folonzo. The width of the forest belt around the river as well as the density of tree individuals increase from north to south. The scale is identical in all pictures.

Fig. 3: Appearance of gallery forests at eight sites in Burkina Faso from north to south. Vegetation density and canopy height increase constantly from north to south. All sites shown here were included in this study.

1.2 West African Climate

The climate of West Africa is driven by the 'Intertropical Convergence Zone (ITCZ)', a low pressure trough located between the northern and southern trade wind belts. The ITCZ is a few hundred kilometres broad, and changes its position throughout the year, oscillating north- and southwards with the zenith of the sun. The latitudinal oscillations of the ITCZ cause a highly seasonal climate in the areas between 30° north and south, which leads to alternating dry and wet seasons and slight temperature changes.

The climate in West Africa changes continuously from north to south, from dry and hot to wetter and warm (fig. 4). Figure 5 illustrates the north-south gradient for four climatic variables that have been shown to influence large scale vegetation structure (Kreft & Jetz 2007, Cowling *et al.* 1994, Nicholson *et al.* 1990, Francis & Currie 2003, Mutke *et al.* 2001, Good & Caylor 2011). The 'mean annual precipitation' (MAP, fig. 5A) increases from less than 100 mm in Mali and Mauritania at the border of the Sahara to over 3000 mm in Liberia and Sierra Leone. In semi-arid and arid areas, precipitation (often as MAP) is a major determining factor of vegetation (Hawkins *et al.* 2003, Sankaran *et al.* 2008, Lane *et al.* 1998) and floristic community composition (Gonzalez *et al.* 2012, Zizka *et al.* 2015a, Schmidt *et al.* 2013, Schmidt *et al.* 2011, Schmidt *et al.* 2017). Increasing MAP has been correlated with higher tree and forest cover (Privette *et al.* 2004, Sankaran *et al.* 2008), higher woody plant biomass (Scholes *et al.* 2002, Bucini & Hanan 2007), higher total plant size (Moles *et al.* 2009, Gonzalez *et al.* 2012, Schmidt *et al.* 2013, Scholes *et al.* 2002), and increased species richness (Mutke *et al.* 2001).

In addition to the change of total MAP, the 'precipitation seasonality' decreases from north to south (fig. 5B). Thus, precipitation is not equally distributed over the year but is concentrated in one or two rainy seasons. In the south of West Africa the rainy seasons are longer, and the differences between the rainy and dry season are less pronounced. In West Africa, precipitation seasonality is the major factor determining growing season length and thus influencing vegetation (Gaughan *et al.* 2012, Good & Caylor 2011, Martiny *et al.* 2006).

Another index to measure the total amount of days suitable for plant growth is the 'length of growing period'. This is the time when temperature and water availability in a region are suitable for plant growth (FAO GeoNetwork). Figure 5C shows the length of the growing period for West Africa. As the temperature in this region is

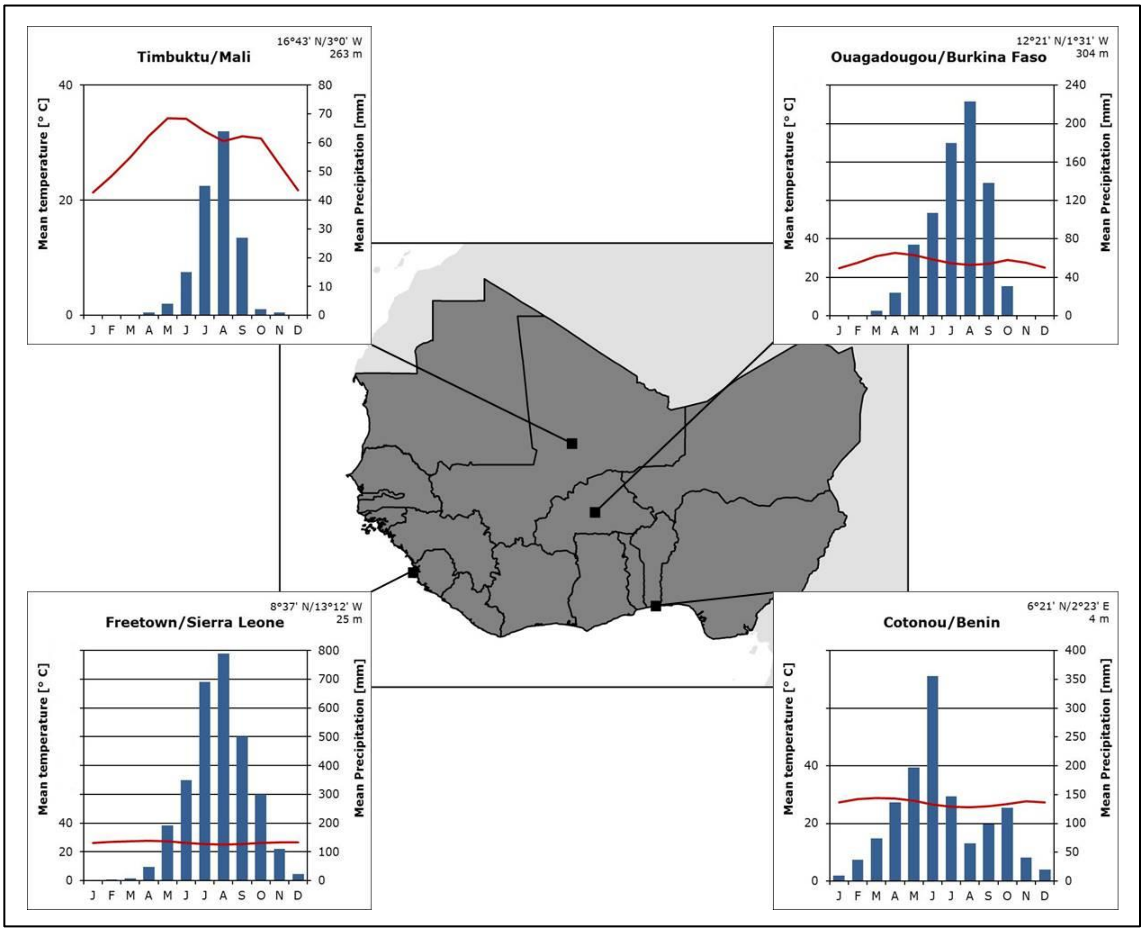

Fig. 4: Climate charts showing annual precipitation and temperature patterns at four representative weather stations along the West African climate gradient. The blue bars show the amount of precipitation per month, the red lines show the mean monthly temperature. From north to south the total precipitation and the length of the rainy season increase. Note the two rainy seasons in Cotonou, the southernmost point. Climate data retrieved from Deutscher Wetterdienst (DWD 2007).

suitable for plants all year long the length of the growing period is strongly connected to precipitation seasonality.

Unlike MAP, 'precipitation seasonality' and 'length of growing period', the 'mean annual temperature (MAT)' slightly decreases from north to south (fig. 5D), from about 30° C in the southern Sahara to about 26° C at the coast. Generally, the discussed climatic factors show a relatively consistent and homogenous gradient from north to south at the regional scale. This is largely due to the absence of larger mountain chains or other geological barriers which could disturb atmospheric circulations and create local climates. The climatic gradient generally leads to a decrease in stressfulness of the environment for plants from north to south.

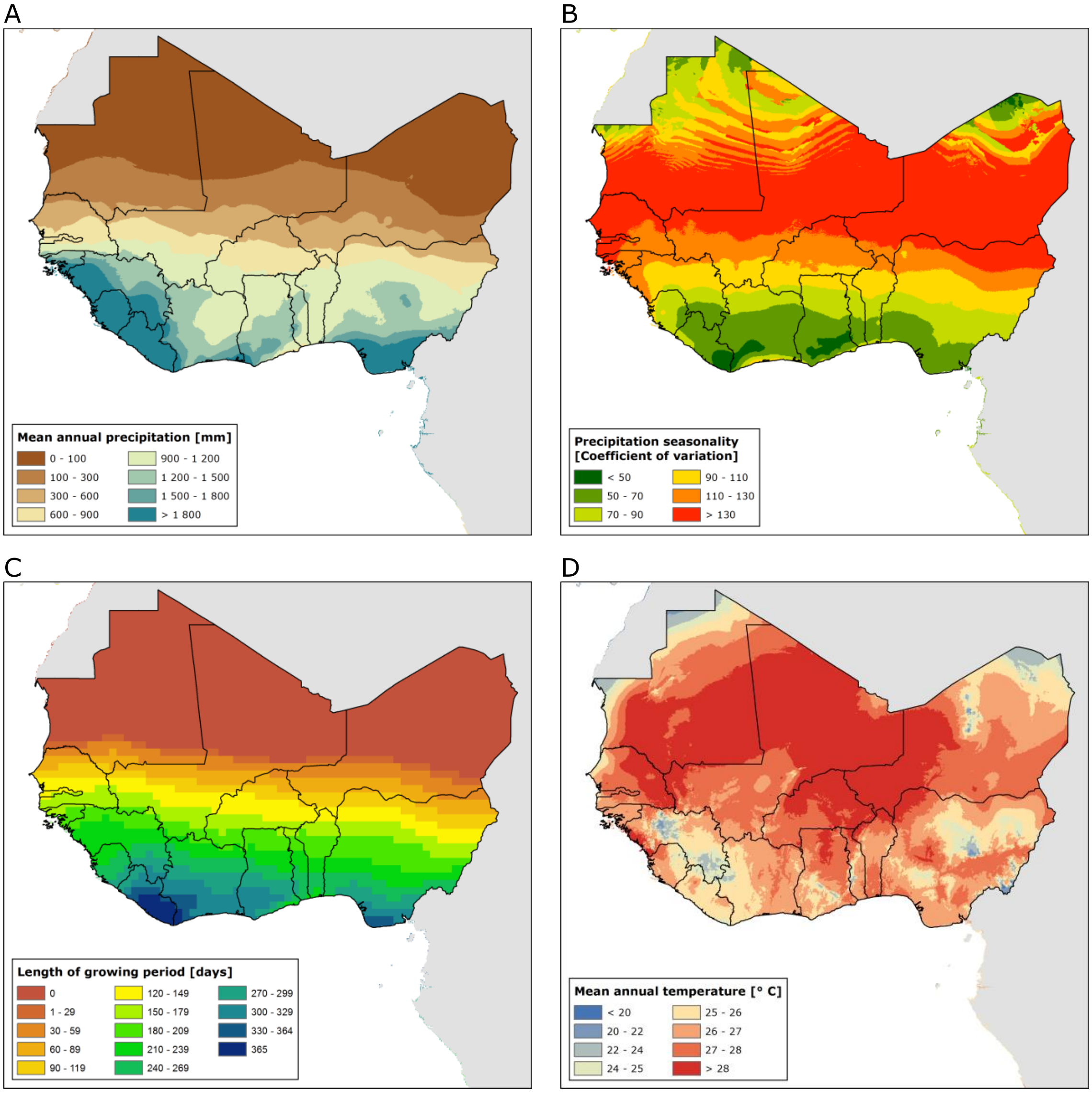

Fig. 5: Four major factors of the West African climate gradient relevant for plant growth. A) mean annual precipitation increasing from north to south; B) mean annual temperature generally decreases from north to south; C) precipitation seasonality (standard deviation/mean), decreasing from north to south; D) length of the growing period, increasing from north to south. Data for A, B, D) from BioClim with 2.5 arc-minutes resolution (Hijmans *et al.* 2005). Data for D) from FAO GeoNetwork with 2.5 arc-minutes resolution (FAO GeoNetwork). Note the almost continuous change of climate due to the absence of mountain ranges in the area.

1.3 West African Vegetation and Flora

1.3.1 Vegetation of West Africa

The vegetation of West Africa is mainly driven by the regional climate gradient. In general, tree cover, tree biomass, vegetation density and vegetation height increase from north to south. The increased vegetation cover can easily be observed on satellite images (fig. 6). The extent of the vegetation cover oscillates northwards during the rainy season and southwards during the dry season (fig. 7). The resulting conspicuous latitudinal bands of vegetation parallel to the equator have fascinated botanists and biogeographers for centuries. The first attempts to comprehensively assess the vegetation patterns in the region, mainly based on analyses of mean annual precipitation and dry season length, date back to the first half of the 20th century (Chevalier 1933, Lebrun 1947, Aubréville 1936, Aubréville 1949a, Aubréville 1949b), followed later by Monod (1957), Trochain (1970), Guillaumet & Adjanohoun (1971).

In a seminal study White (1983) classified the vegetation of West Africa into 12 different broad categories (fig. 8). According to his scheme, close canopy forests are confined to latitudes below 7.5° north. Real tropical rainforests only exist in the southern parts of the forested areas towards the Atlantic coast. These southern rainforests are divided into a western part (Upper Guinean Forest) and an eastern part (Lower Guinean Forest) isolated by a stretch of savanna vegetation called the "Dahomey Gap" (fig. 8). The vast majority of West Africa, roughly an area of about 5 million km^2 between 7.5° and 15° north, is covered by savanna (Olson *et al.* 2001, Mistry 2000). Savanna is a notoriously vaguely defined vegetation type, but generally comprises a continuous grass layer and a discontinuous tree cover (somewhere between 5 – 80 %; Ratnam *et al.* 2011, Scholes & Archer 1997, House *et al.* 2003). In West African savannas, tree and shrub cover seldom reaches more than 40 % (Mistry 2000).

White (1983), recently supported by Linder *et al.* (2012) and Da (2010) recognized three different zones of savanna vegetation in West Africa from north to south: the **Sahel**, the **Sudanian** and the **Guinean**.

The **Sahel** is defined by low precipitation (<500 mm) and a long dry season (up to ten months). Tree cover is about 10 %, trees and shrubs hardly reach above 5 meters. Typical woody plant species are *Acacia ehrenbergiana, Acacia laeta, Acacia tortilis, Commiphora africana, Balanites aegyptiaca* and *Boscia senegalensis* (Mistry 2000). The herb layer is dominated by grasses including species of the genera *Cenchrus, Aristida, Panicum*, *Schoenefeldia* and *Tragus*.

The **Sudanian zone** has a higher precipitation (500-1000 mm) and a shorter dry season (5-7.5 months). A wide distribution of most species makes a more detailed classification of the vegetation of this zone somewhat difficult (although Guinko

(1984) recognized a distinction between the Southern and Northern Sudan zone in Burkina Faso, see section 1.3.3). Common woody elements of the Sudanian zone include *Isoberlinia doka*, *Afzelia africana*, *Burkea africana*, *Daniellia oliveri* and various species of *Terminalia.* The grasses in this zone are generally taller and include perennial species of the genera *Andropogon* and *Hyparrhenia*.

The **Guinea zone** is even wetter (1000-1750 mm) and the dry season is relatively short (2.5 – 5 months). Typical phenomenons of the Guinea zone are large communities dominated by a single woody species, often *Isoberlina doka*, *Isoberlinia tomentosa*, *Monotes kerstingii* or *Uapaca togoensis*. The number of tree species in this zone is high compared to the two other zones, and amongst others includes large, iconic species such as *Sclerocarya birrea*. Grasses in the Guinean zone are often perennial and tall (up to 3m), with many species of *Andropogon*, *Hyparrhenia* and *Pennisetum*.

The climate in the region, in particular the dry seasons, has led to a specific phenology in many woody plants. De Bie *et al.* (1998) recognized three major life history strategies of woody plants in West Africa with regard to phenology: evergreen, semi-evergreen and deciduous. In addition to leaf growth, flowering and fruiting are seasonal as well. In herbaceous species the major adaption to the dry seasons is a therophytic or hemicryptophytic life-form, with most of the above-ground structures dying back during the dry season. Besides the climate gradient, nutrient availability and fire are important drivers of savanna vegetation in West Africa and there is a strong anthropogenic influence, not addressed here. The West African savannas are generally considered rather nutrient poor (Mistry 2000). Fires are a common and regular feature (Barbosa *et al.* 1999) and have been recorded from the region since 40,000 years (Bird & Cali 1998).

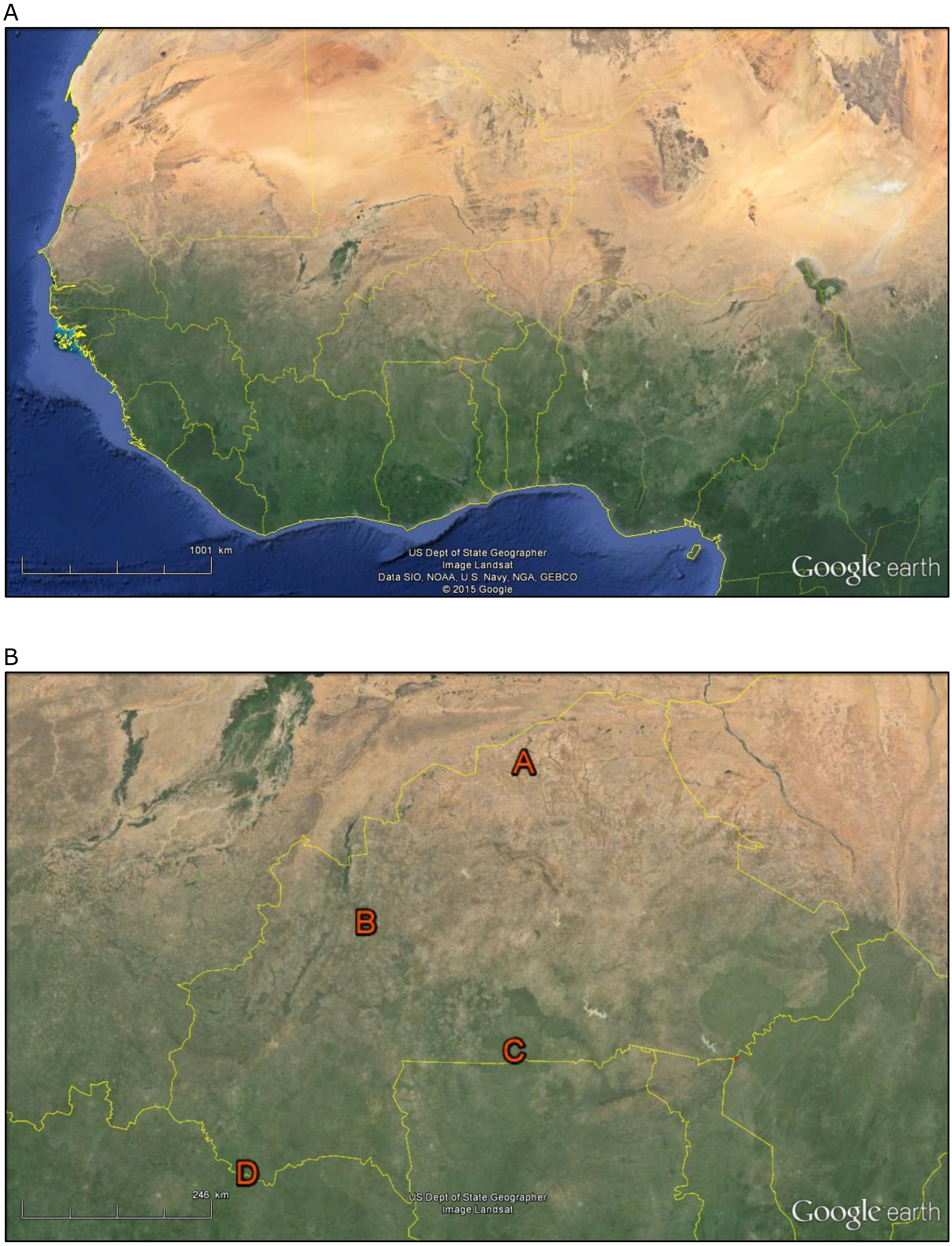

Fig. 6: Satellite images of the study area. (A) West Africa; (B) Burkina Faso. The capital letters in subfigure B refer to locations shown in figure 2. The amount of green vegetation increases from north to south. Downloaded from Google Earth in October 2015. Note that the images are composed from different observation times. See figure 7 for seasonal changes.

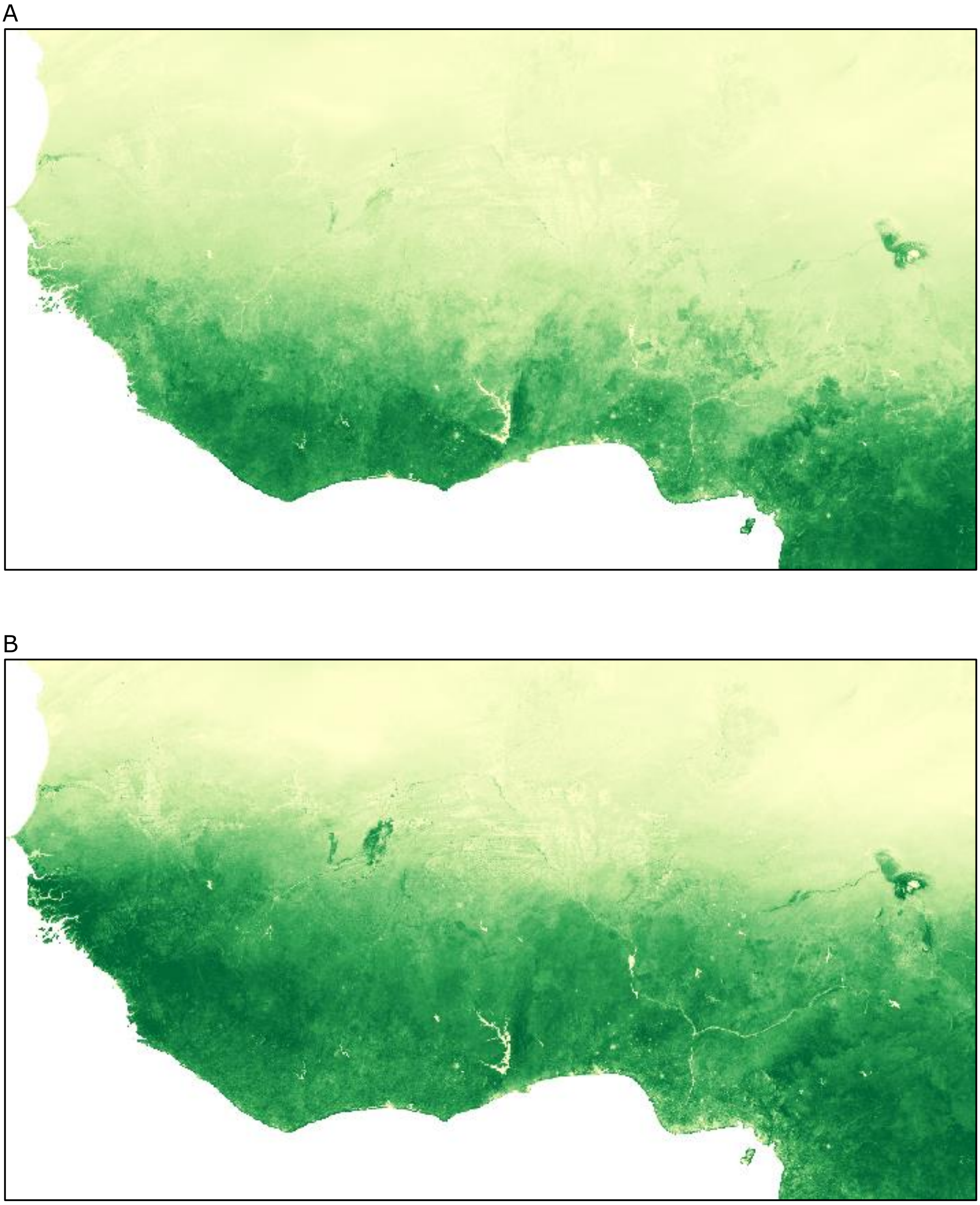

Fig. 7: Seasonal changes in vegetation cover in West Africa. A) During the dry season; B) During the rainy season. Derived from USGS (https://earlywarning.usgs.gov/fews/search/Africa/West Africa).

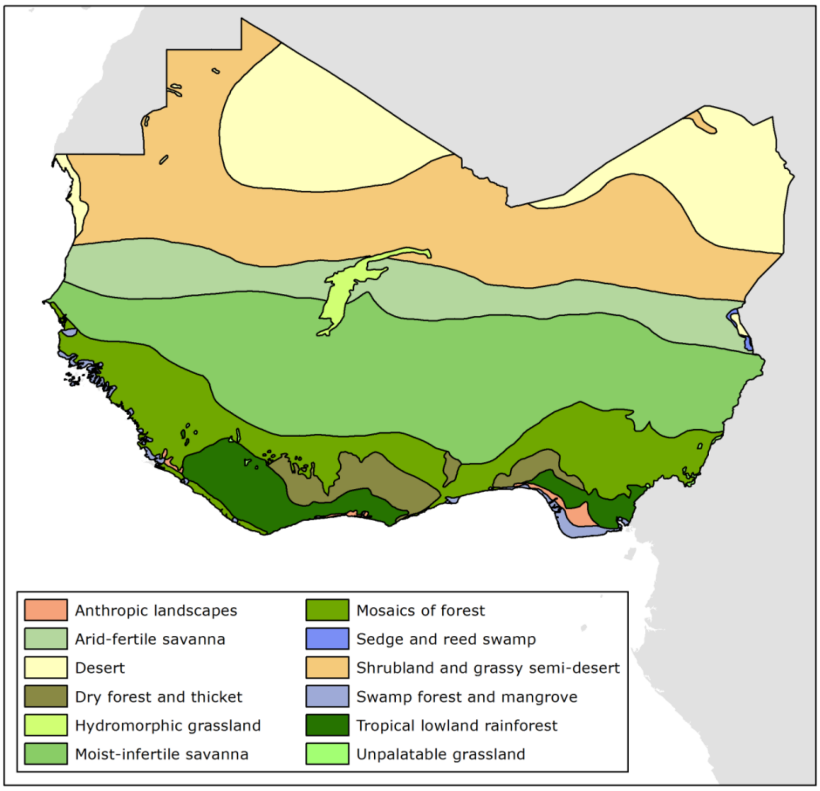

Fig. 8: The vegetation of West Africa adapted from White (1983). The large-scale patterns are latitudinal bands following the regional climate gradient. Vegetation changes from desert in the north to tropical rainforest in the south. Note the Dahomey Gap with slightly drier conditions between 0 and 3° E at the coast, preventing rainforest, and separating the Upper and Lower Guinean rainforests.

1.3.2 Flora and Phytodiversity of West Africa

The Flora of West Tropical Africa (Hutchinson & Dalziel 1954) includes 229 families, 1743 genera and 7072 species of angiosperms, gymnosperms and pteridophytes, with the vast majority being angiosperms. These numbers are still the most comprehensive estimates. More recently, White (1983) estimated 2750 higher plant species within the Sudanian zone of West Africa and based on interpolation Mutke & Barthlott (2005) and Barthlott *et al.* (2005) estimated 1500 – 2000 species of angiosperms in a standard area of 10,000 km^2 in the Guinean zone, 500 – 1500 in the Sudanian zone and 200 – 500 in the Sahel.

The species richness in most parts of West Africa is relatively low compared to other regions of the continent. This is true not only in comparison to high diversity areas such as the Congolian rainforest or the Cape floristic region, but also in comparison to climatically more similar regions, as for example the East and South African savannas (Linder 2001, Barthlott *et al.* 2007). No diversity hotspots have been defined in the savannas of West Africa and only the rainforests in the Guinean zone on the Atlantic coast have been noted as high diversity areas (Barthlott *et al.* 2007, Mutke & Barthlott 2005, Linder 2001, Myers *et al.* 2000, Küper *et al.* 2004). The relatively low diversity coincides with very low levels of endemism (Linder 2001, Linder 2014), a low range size rarity (Barthlott *et al.* 2007, Küper *et al.* 2004), and a low turnover of species among neighbouring areas (Linder *et al.* 2012) meaning, that most species in the region have large distribution ranges (but see Da (2010)). The low diversity and degree of endemism have been attributed to the dry climate (Mutke *et al.* 2001, Da 2010) and low topodiversity (Mutke *et al.* 2001, Barthlott *et al.* 2007). The West African savanna comprises a variety of animal species, including large herbivores such as elephants and giraffe, carnivores including lions, and a diverse bird fauna.

A lack of sampling and deficiency of distribution data is an issue for research almost everywhere in Africa, as in most tropical regions. In the study area, undersampling is not as severe as in other regions (Küper *et al.* 2006, Kier *et al.* 2005), but sampling in Burkina Faso (BFA) is uneven (Schmidt 2006) and gallery forests (GFs) are generally undersampled. The majority of species recently reported for BFA for the first time was found in GFs (César *et al.* 2009) and GF species are a major part of species classified as endangered in BFA (Schmidt *et al.* 2017).

1.3.3 Vegetation of Burkina Faso

The vegetation of Burkina Faso spans the Sudanian and Sahelian zones of White (1983), Da (2010) and Linder *et al.* (2012) and the climatic gradient is clearly the most important driver of vegetation patterns on the national scale (M. Schmidt *et al.* 2010). In particular, Guinko (1984) distinguished two phytogeographic domains: the Sahel, further divided into the Sahel *sensu stricto* (hereafter called **Sahel**) and the sub-Sahelian sector (hereafter called **sub-Sahel**) and the Sudanian, further divided into the 'sector sudanian septentrional' (hereafter called **North Sudanian zone**) and the 'sector sudanian meridional' (hereafter called **South Sudanian zone**) (fig. 9).

In the **Sahel** precipitation is below 600 mm with 7 – 9 months of dry season. The flora is dominated by species from the Sahel or the Sahara, typical species include *Acacia* spp., *Andropogon gayanus*, *Aristida* spp., *Cenchrus brocchiana*, *Grewia tenax*, *Merremia pinnata, Tetrapogon cenchriformis* as well as *Anogeissus leiocarpa, Mitragyna inermis, Acacia ataxantha* and *Acacia seyal* in GFs (Guinko 1984).

The **sub-Sahel** in Burkina Faso is located between the 13th and 14th parallel and precipitation is between 600 and 750 mm with 7 – 8 months of dry season. The vegetation is dominated by Sahelian and Saharan elements, but generalist from the Sudanian are also present. Typical species include *Bauhinia rufescens, Capparis tomentosa*, *Cenchrus biflorus*, *Dalbergia melanoxylon*, *Euphorbia balsamifera*, *Grewia flavescens*, *Combretum glutinosum*, *Combretum micranthum* and *Acacia macrostachya*.

In the **North Sudanian zone**, precipitation is between 750 and 1000 mm with 6 – 7 months of dry season. Iconic species of this zone include *Vitellaria paradoxa*, *Parkia biglobosa*, *Lannea microcarpa, Adansonia digitata*, *Tamarindus indica*, and *Acacia albida*, but the vegetation of this sector is severely altered by cultivation.

The **South Sudanian zone** is characterized by a precipitation between 1000 and 1400 mm with 4 – 6 months of dry season. Forests and GFs are common in this zone. The most characteristic species is *Isoberlinia doka;* other important species include *Cola laurifolia, Daniellia oliveri, Khaya senegalensis, Pterocarpus santalinoides* and *Dialium guineense.*

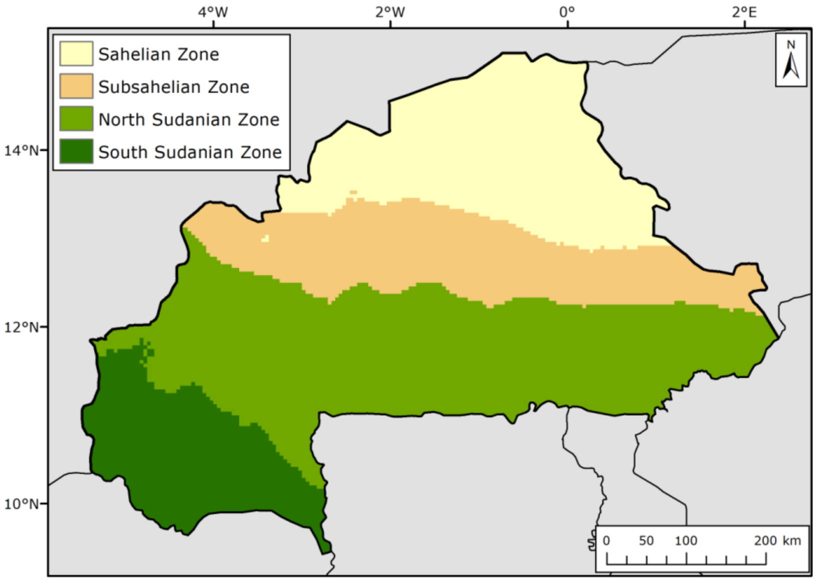

Fig. 9: The vegetation of Burkina Faso adapted from Guinko (1984). The zones are defined by characteristic floristic composition and vegetation, which is tightly related to the regional climate gradient. Generally, vegetation shifts from xeric savannas in the north to more mesic woodlands and forests in the south. The names have been translated to English: Sahelian zone = secteur sahélien strict, sub-Sahelian zone = secteur subsahélien, North Sudanian zone = secteur soudanien septentrional and South Sudanian zone = secteur soudanien meridional.

In all phytogeographic zones phanerophytes and therophytes are the most speciose life-forms, but the importance of phanerophytes increases from north to south while the importance of therophytes and hemicryptophytes decreases (Schmidt 2006, Schmidt *et al.* 2013, Zizka *et al.* 2015a). For woody plants, plant size increases and the degree of spinescence decreases from north to south (Schmidt *et al.* 2013). Flowering season also has a strong latitudinal pattern: in the north species flower mostly in the rainy season, in the south more commonly in the dry season. In all phytogeographic zones grasses are the most important herbs. For grasses Schmidt *et al.* (2011) found a change from short, mostly therophytic species in the north to taller, often perennial species in the south.

Generally, the different phytogeographic zones are not separated by abrupt borders, but changes are rather gradual. The local vegetation and flora within the different zones can be heterogeneous and deviate considerably from the large scale patterns. This is especially the case in GFs and other azonal vegetation, such as inselbergs (Müller 2008, Porembski *et al.* 1994, Sarthou 2002), hard lateritic soils ("bowé", Zwarg *et al.* 2012), termite mounts (Kirchmair *et al.* 2012) and the stripped thickets ("brousse tigrée", Thiombiano *et al.* 2013). Therefore, GFs are of particular importance as habitat for plant species that otherwise do not occur in BFA, and also play an important role as habitat and food source for wildlife and humans.

The natural vegetation of BFA is today almost exclusively present in protected areas (Hahn-Hadjali *et al.* 2010) and climate change and anthropogenic influence pose a serious threat to these remnants (e.g. Schmidt *et al.* 2013b). BFA covers a substantial part of the drier part of the West African climatic gradient (300 to 1200 mm) and comprises a major part of the regional savanna vegetation and savanna flora. Therefore, the national flora and vegetation can be considered as representative for the region (Zizka *et al.* 2015a) and thus, conclusions regarding conservation might be suggestive for the regional scale.

1.3.4 Flora and Phytodiversity of Burkina Faso

BFA comprises 2,067 plant species (including ferns) in 753 genera and 145 families (Thiombiano *et al.* 2013). The most species-rich families are Fabaceae, Poaceae, and Cyperaceae. The national species richness follows the climate gradient, mirroring the situation of the entire region. Taxonomic diversity is lowest in the Sahel with 518 total species, 179 species per 10,000 km^2, 265 genera, and 73 families. Diversity increases from north to south throughout the three remaining zones to peak in the South Sudanian with 1,410 total species, 235 species per 10,000 km^2, 614 genera and 131 families (Zizka *et al.* 2015a, Schmidt 2006).

The southeast of BFA, around the W National Park and, in particular, the southwest around the sandstone massif of Mount Ténakourou are national centres of plant diversity (Zizka *et al.* 2015a, Schmidt *et al.* 2017). The W National Park is a trans-frontier protected area with multiple reserves on the Burkinian side and includes the Arly National Park and the Pama Partial Reserve. The complex has been shown to comprise a good representation of the Sudanian flora (Mbayngone *et al.* 2008b, Ouédraogo *et al.* 2011). One of the most striking features of the flora of BFA is the large average range size and the surprisingly low number of endemics. Most of the species recorded for BFA occur throughout Africa, or at least West Africa (Zizka *et al.* 2015a). Only one species, *Isoetes jaegeri*, is endemic to the country.

Of the total 2067 species 38 % can be considered rare in BFA (Zizka *et al.* 2015a) and 14 % (284 species) have been classified as threatened or near-threatened (Schmidt *et al.* 2017). These nationally rare and threatened species are mostly confined to the south of the country and mainly include hemicryptophytes and geophytes, life-forms mostly underrepresented in the national flora. Strikingly, the threatened species include an unproportioned high number of plant families typical for forest habitats. Schmidt *et al.* (2016) classified almost one third of all Rubiaceae and Vitaceae species as threatened. About 50 % of the species known to BFA have a reported traditional use, and traditional plant use is still today a major source of income and medical treatment for large parts of the population (Zizka *et al.* 2015b).

1.4 Climate and Vegetation through Time

The last 2.6 million years of Earth history (the epochs of Pleistocene and Holocene) were marked by cycles of climatic fluctuation, manifesting in cold periods with ice sheets covering large parts of the northern hemisphere ("glacials") and warm periods with reduced ice coverage ("interglacials"). The exact drivers of these cycles are still under debate, but regular Earth's orbit variations (Milankovitch cycles) such as eccentricity and obliquity of the Earth's axis seem to be one important factor

(Berger 1988, Zachos *et al.* 2001, Kashiwaya *et al.* 2001). The fixation of large amounts of water in the ice sheets during the glacials had multiple effects on global climate, including sea-level changes, changes in ocean currents and changes of local climate. In West Africa, glacial periods most likely caused a drier and slightly colder climate, whereas interglacials were linked with wetter conditions (Hewitt 2000, Jolly *et al.* 1998, DeMenocal 2004).

Eleven glacial cycles are recorded for the Pleistocene, with the last glacial period from around 110,000 to 12,000 years before present (BP). The glacial maximum in this period ("Last glacial maximum", LGM) occurred between 25,000–15,000 years BP (with its climax at about 19,000 years BP), which in West Africa led to especially dry conditions (Dupont & Weinelt 1996, Gasse 2000, Livingstone 1975). The end of the LGM marks the end of the last glacial period and the shift from Pleistocene to Holocene. It was also the start of the current interglacial period. In West Africa the climate during the early and especially during the mid-Holocene was predominantly wet and warm.

The cyclic changes of water availability in West Africa triggered corresponding cyclic changes in vegetation. Most likely, the vegetation bands observed today oscillated north- and southwards, with a northward shift of forests in wet interglacials and a southward shift during dry glacial periods (fig. 10) (Adams & Faure 1997, Jolly *et al.* 1998, Cowling *et al.* 1994). In the same manner the wet conditions during interglacials probably also led to an expansion of forests on a local scale, whereas dry conditions generally led to forests retractions. During the LGM the vegetation zones were shifted considerably southwards, with most parts of Burkina Faso (BFA) covered by vegetation similar to what today is observed in the Sahel or even the Sahara (fig. 10A). The conditions during the mid-Holocene likely resembled the present day conditions with a slightly more favourable climate and thus northwards shifted vegetation zones (fig. 10B).

During the LGM the West African rainforests were strongly reduced and fragmented compared to today (Dupont & Weinelt 1996, Leal 2004). The Dahomey Gap was much larger and remnants of rainforest were left only at the southernmost tip of West Africa, at the Cameroonian coast and the central Congo basin (fig. 10A). Savannas and open woodlands covered a larger area than today (Dupont & Weinelt 1996, Jolly *et al.* 1998, Cowling *et al.* 2008) and the Sahara desert was expanded to the south (Ray & Adams 2001, Cowling *et al.* 2008, Handiani *et al.* 2012). The end of the LGM started with a first warming period with increased precipitation at approximately 17,000-16,000 years BP (Gasse 2000). As a consequence the West African rainforest started expanding during the glacial-interglacial transition at about 15,000 years BP (Dupont & Weinelt 1996).

In the early Holocene (ca. 12,000 years BP) the final stage of deglaciation was reached, leading to a well documented increase in precipitation (see Salzmann *et al.* 2002 and references therein, Jolly *et al.* 1998) and savannas abruptly switched to rainforests in large parts of southern West Africa due to a strong increase in precipitation (Maley 1991). This was followed by a continued expansion of rainforest (Dupont & Weinelt 1996) spreading out from fragmented refugia in the Congo basin and on the Cameroonian coast (Leal 2004). The expansion of forests probably also led to a closure of the Dahomey Gap with a continuous forest from the Congo basin along the coast (Dupont *et al.* 2000, Maley 1991, Salzmann *et al.* 2002) (fig. 10B). At the same time large parts of the Sahara were covered by savanna (Adams & Faure 1997). There are numerous evidences for a "green" Sahara from the Early to the mid-Holocene (8,000–5,000 BP) (see Gasse 2000 and references therein). In the late Holocene (4,000-2,000 years BP) the climate conditions became drier again, the rainforest retracted and the Dahomey Gap re-opened (Shanahan *et al.* 2006, Salzmann & Hoelzmann 2005). This retraction of forest continued after 3,000 years BP probably due to increasing aridity but potentially also caused by human land-use (Livingstone 1975) leading to the vegetation cover observed today (fig. 10C).

Gallery forests (GFs) might have played a pivotal role during the vegetation oscillations in the Pleistocene. Due to the increased water availability through the rivers they might have acted as local refugia for forest species during dry cycles, expanding species ranges northwards just as it is the case today. Furthermore, they might have acted as south- and northward dispersal corridors for forest species when shifting into a dry glacial period, and when climate changed into more mesic interglacial conditions, respectively. A better understanding of the role of GFs is urgently warranted, as processes and consequences of current climate change might be comparable to Pleistocene climate changes.

The future climate projections for West Africa are controversial and strongly dependent on the development of anthropogenic CO_2 emissions. There are different projections on how greenhouse gas emission and thus global warming will change until 2100, depending on different factors such as population size, lifestyle, land-use patterns and economic activity (IPCC 2014). For these projections four different 'Representative Concentration Pathways' (RCPs) are used. In this study the intermediate RCP 4.5 scenario is used in which the total radiative forcing is assumed to stabilise before 2100 by means of strategies and technologies for reducing greenhouse gas emissions (Clarke *et al.* 2007).

Africa is the continent considered most vulnerable to climate change (IPCC 2001). Climate change will cause severe changes for plant distribution in sub-Saharan Africa and will have a generally negative impact on plant diversity (Da 2010) with a potential reduction in crop yields by 15 % in West Africa (Roudier *et al.* 2011). Suitable areas for many plant species will decrease and/or shift and temperature is likely to increase. The prediction of precipitation for the 21st century is generally difficult and projections often have a huge variability (Hawkins & Sutton 2011, Deser *et al.* 2012, Druyan 2011). This is especially the case for West Africa, due to difficulties with prediciting the behaviour of the monsoon system and the Gulf of Guinea with changing temperature (Druyan 2011, Paeth *et al.* 2011). Consequently, predictions for precipitation for West Africa differ considerably between models and areas, ranging from substantial increases in preciptitation to severe decreases (Niang *et al.* 2014, Cook & Vizy 2006). No clear consensus exists, but more models tend to a slight decrease in precipitation, especially in the second half of the 21st century. However, changes in precipitation might differ between the parts of West Africa. By 2085 up to 50 % of plant species in sub-Saharan Africa are projected to lose their entire suitable habitat (McClean *et al.* 2005), and only a few species from dry habitats will increase in range size. These shifts in plant species distribution will lead to large geographical changes in species composition and to a shift of vegetation zones. As the distribution of plants in sub-Saharan Africa is mainly determined by the amount of precipitation, the West African forests and in particular the Guineo-Congolian forest/rainforest are threatened by the projected changes in climate (McClean *et al.* 2005, Da 2010). Over 95 % of forest species are projected to decrease their distribution range by 2085 (Da 2010).

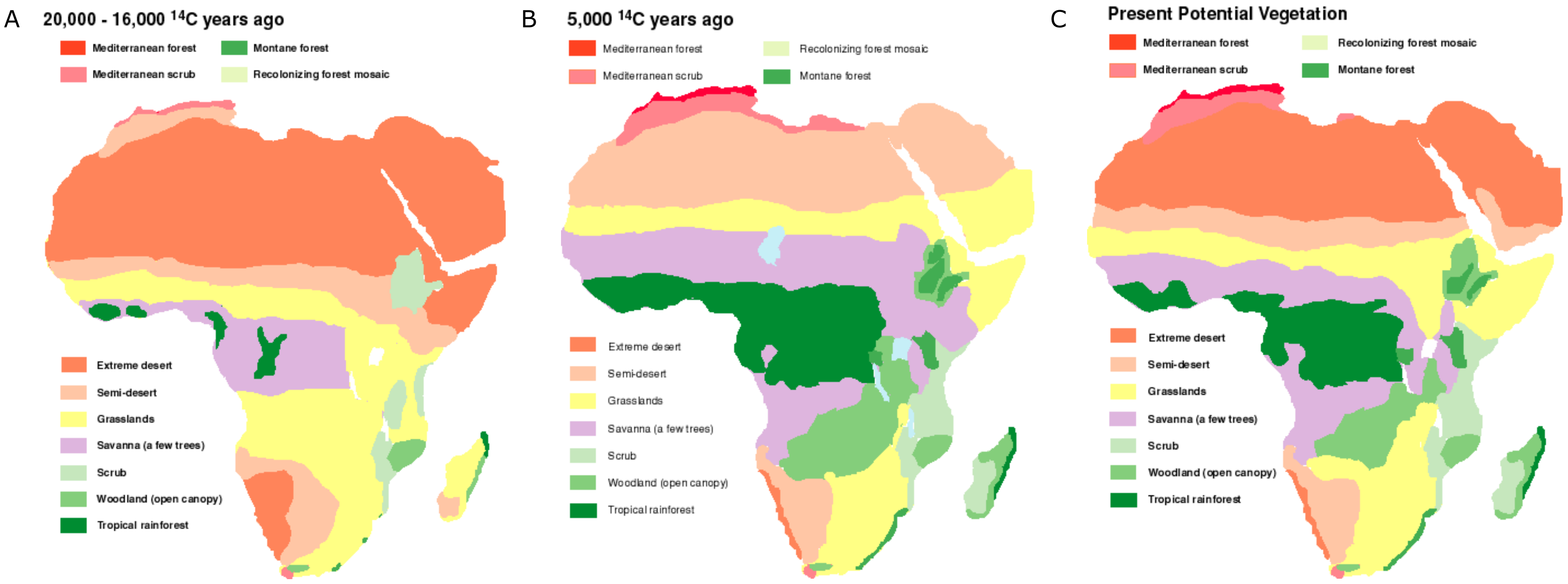

Fig. 10: The West African vegetation during the last 20,000 years. A) Last Glacial Maximum; B) Mid-Holocene; C) present day potential vegetation (reprinted from Adams & Faure 1997). Following climate changes rainforest and other mesic vegetation contracted during the dry period at the LGM and expanded until the mid-Holocene, where climate was substantially wetter. During the LGM rainforest was restricted to few refugia close to the equator. During the mid-Holocene the rainforest was covering half of West Africa and the Dahomey Gap was closed. This was also the time when the savanna extended far into what today is the Sahara desert. Since the mid-Holocene climate has become drier and forests have retracted towards the equator, leading to the re-opening of the Dahomey Gap.

1.5 Aims of this Study

The aim of this study is to improve our understanding of the West African gallery forests (GFs), their floristic composition, vegetation history and prospects under climate change. In particular, their response to past and future climate changes, their role as refugia and dispersal corridors as well as conservation perspectives are investigated. In three chapters I use the GFs of Burkina Faso (BFA) as a model for West African GFs and combine information on ecological preferences and human plant use, ecological niche modelling through time and analyses of the genetic population structure to understand the response of GFs to climatic change, and the mechanisms shaping this response. Until now West African GFs have primarily been studied from a floristic and phytosociological perspective using rélevées and inventory data. With this study I hope to amend to this literature with a larger scale from a genetic and biogeographic point of view. A better understanding of GFs is urgently needed for effective conservation, as the anthropogenic pressure on these ecosystems is steadily increasing. The three chapters of this thesis use three different angles on GF vegetation:

I. Plant Diversity of Gallery Forests in Burkina Faso

GFs are unique, azonal habitats that harbour a very specific flora. In BFA, where traditional plant use is still common, this GF flora is of high economic, social and medical importance to large parts of the population. However, a national scale synthesis of flora and diversity of GFs taking traditional plant use into account is still missing. In this study, I compiled a dataset of habitat preferences of all GF species known to Burkina Faso based on existing literature, and then combined this dataset with distribution data and ecological and taxonomic information to compare the diversity and the taxonomical and functional composition of the GFs with the total national flora. Furthermore, I used this dataset to evaluate the role of GF flora for traditional human use, with a focus on traditional medicine. Specifically, I address five major questions with section 3.1 this thesis:

1. Where are centres of GF diversity in BFA?
2. How does the flora of GFs differ from the national flora?
3. Which taxonomic groups mainly contribute to the species richness in GFs?
4. Are GF species used more intensively or for specific purposes?
5. Can the floral composition of GFs explain their importance for the plant-use by local human communities?

II. Distribution Range of Gallery Forest Species

During the predominantly dry interglacials of the Pleistocene, GFs might have acted as local refugia for forests species in the latitudes of current day BFA, and/or as corridors for the dispersal of forest species during periods of climatic change. In the face of current climate change GFs might, once again, act as local refugia and dispersal corridors for forests species in West Africa. Starting from the list of GF species, I compiled a dataset of occurrence records for 20 important GF tree species and used it together with regional climate layers to model the distribution of GF species in West Africa at four different time slices. Additionally, I estimated the 'extent of occurrence' (EOO) and 'area of occupancy' (AOO) for the study species and performed an automated conservation assessment following criterion B of the IUCN. Specifically, I address three questions in section 3.2:

1. How important is climate as determining factor for GF species distributions?
2. How did the climate conditions in the past effect the distribution of GF species, and what was the extent of forests and GFs in West Africa at the LGM (the driest point in the last 120,000 years) and the Holocene climate optimum (the potential wettest phase of the last 120,000 years)?
3. How will climate change influence the distribution of GF species in the future?

III. Genetic Structure of Gallery Forest Species in Burkina Faso

The West African forests have been subject to multiple extension and retraction cycles related to climate fluctuations during the Pleistocene. In this context, GFs might have acted as local refugia and/or recolonization routes for forest species. In section 3.3 I use AFLP markers to investigate the genetic population structure of four GF species typical for Burkina Faso and West Africa. Specifically, I test if the population structure reflects Pleistocene vegetation dynamics and supports the hypothesis of river basins as corridors of northwards dispersal. Furthermore, I used the AFLP data in a species-tree diffusion model approach to reconstruct the historical biogeography of GFs in BFA and to test the correlation genetic structure and environmental drivers. The study species include species with different range size and dispersal mode: *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Paullinia pinnata* and *Pterocarpus santalinoides*. Specifically, I address five questions in sections 3.3, 3.4 and 3.5:

1. Does the genetic structure of the study populations show patterns of local refugia during the LGM?
2. Does the population structure correlate with the major river basins, suggesting river basins as dispersal corridors for forest species?
3. Which re-colonization and dispersal pattern is supported by the genetic population structure?
4. Is the genetic population structure related to dispersal mode of species?
5. Is the genetic population structure related to environmental factors, indicating different ecotypes rather than an imprint of Pleistocene vegetation dynamics?

2 Material and Methods

2.1 Study Area

In this study, Burkina Faso (BFA) was used as a model to explore the biodiversity and biogeographic history of West African gallery forests (GFs). The flora of BFA has been considered representative for entire West Africa (Zizka *et al.* 2015a, Schmidt *et al.* 2017). Indeed, BFA is especially suited as a model for the region for the purpose of this study, because of the relative abundance of GFs and the countries' central position on the regional climate gradient. BFA covers a substantial part of this gradient and comprises most of the vegetation types of the West African savanna belt, from moist Sudanian forest to xeric Sahelian sub-desert. Thus, it also covers the northern fringe of forest occurrence in West Africa, and climate changes are likely to cause, and have caused, significant forest retraction and expansion within this area. Additionally, the division of the countries hydrology into three major river basins allows testing the hypothesis on correlation between genetic population structure and river basins, and the function of riverbeds as dispersal corridors and refugia for GF species.

BFA covers approximately 270,000 km² between 9-15° N and 6-3° W in central West Africa. The country is situated on a plain between 300-400 m above sea level – major mountain chains are absent. The most important elevations are the Gobnangou Mountains and the massif of Mount Tenakourou (the highest point in the country, 749 m). BFA has a population of about 18 million with most of them, 13 million, living in rural communities (Central Intelligence Agency 2015), with an average population density of 52 inh./km^2. There are three national parks, one UNESCO biosphere reserve, 15 sites protected under the Ramsar Convention on Wetlands, 12 nature reserves and many areas under local protection, adding up to a total area of 42,000 km^2 in the country (Belemsogbo *et al.* 2010).

2.1.1 River Systems and Watersheds

The hydrology of BFA is governed by the Niger, the Volta and the West Coast river systems. These three watersheds cover large parts of West Africa, and are the major system of the region in terms of size and run-off.

The Niger is the third largest African river (ca. 4,100 km long) after the Nile and the Congo and the longest in West Africa. It originates in the mountains of Guinea, flows in northeastern direction until it touches the south of the Sahara closed to Timbuctoo. From there the river turns south-eastwards and opens into the Gulf of

Guinea on the Nigerian coast. The size of its watershed is approximately 2.3 million km² (FAO 1997) draining a large number of different ecosystems and vegetation zones from the Guinea mountain rainforest, different types of savanna to the Sahara desert (fig. 11). Of the total area of the Niger River basin only 3.4 % are situated in BFA while the Niger River basin covers 28.0 % of the total area of Burkina Faso (FAO 1997).

The Volta basin is the next important watershed in West Africa. It is formed by three rivers: the Black Volta (Mohoun), the Red Volta (Nazinon) and the White Volta (Nakambé). These three rivers originate in BFA and flow southwards towards the Ghanaian coast. The size of the Volta watershed is approximately 394,000 km² (FAO 1997). It ranges from the border to Mali in western BFA, over most of west and south BFA across almost entire Ghana to the Gulf of Guinea (fig. 11). Of the total area of the Volta basin 46.4 % are situated in BFA while the Volta basin covers 66.8 % of the total area of BFA (FAO 1997).

The Comoé river system forms the Burkinian part of the West Coast basin, which groups all basins draining the area from Senegal to Nigeria and rises in the southwest of BFA. The Comoé flows southwards in the direction of the Ivory Coast and flows into the Gulf of Guinea. The size of its watershed is approximately 79,000 km². The watershed of the Comoé river system ranges from the southwesternmost part of BFA across the western Ivory Coast to the Gulf of Guinea (fig. 11). Of the total area of the West Coast basin 1.5 % are situated in BFA while the West Coast basin covers 5.2 % of the total area of BFA (FAO 1997).

2.1.2 Fieldwork and Study Sites

The plant tissue for the genetic analyses and the geographic occurrences for the distribution modelling of the study species were collected during fieldwork in BFA in May-June 2009 at the beginning of the wet season. The study sites were located in GFs throughout the country, between 9.70° - 14.32° N and 5.42° - 0.71° W (fig. 11). The study sites were located in GFs close to the rivers, with a maximum geographic spread through the country and to cover the four phytogeographical zones and the three major watersheds of the country (fig. 9, fig. 11). Leaf tissue samples of three individuals per study species were collected at each site for AFLP analysis. Sampling was performed in 200 m transects parallel to the river bank. The fieldwork was prepared using previous fieldwork, knowledge of local botanists and remote sensing information, but was nevertheless often challenging, and sometimes surprising, due to problems with infrastructure and accessibility, but also due to other factors such as illegal logging and game encounter.

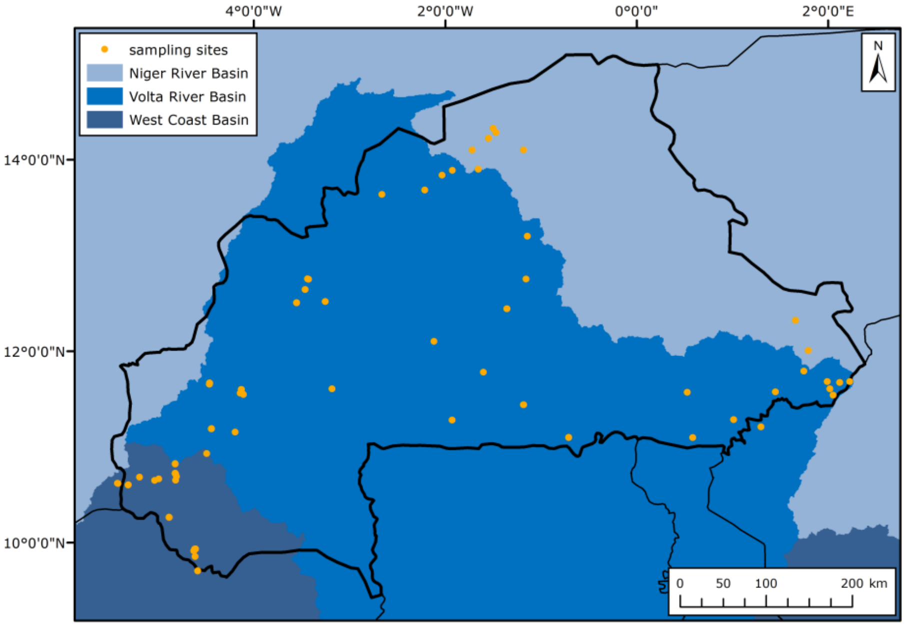

Fig. 11: The three major watersheds of Burkina Faso and the sampling sites for tissue of four characteristic gallery forest species. The Volta basin covers large parts of the country area (FAO GeoNetwork). Leaf tissue samples of three individuals per study species were collected at each site for AFLP analysis. Sampling was performed in 200 m transects parallel to the river bank.

2.2 Diversity, Flora, and Plant Use Data

A database of species habitat preferences for all species with available data known to Burkina Faso (BFA) was compiled based on the recently published checklist of BFA (Thiombiano *et al.* 2013), to give an overview of the flora of gallery forests (GFs) and to evaluate their importance for the national biodiversity. Species were assigned to seven different habitats (savanna, forest, savanna & forest, GF, ruderal, inselberg, aquatic) based on an automated, detailed key-word query. Those species classified as GF species were manually checked against literature (Berhaut 1971, Hutchinson & Dalziel 1954, Aubréville 1936, African Plants Database 2012, Arbonnier 2002, Coates Palgrave 2005, Tropicos.org), and species not occurring in GFs were removed from the list. The final list of GF species comprised 307 species ("GF species" hereafter; see annex 9.4). These species were allowed to also occur in other habitats meaning they are not exclusively found in GFs. This list of GF species was then combined with external datasets, to compare the diversity patterns of

GF species in BFA, the taxonomic and life-form composition of GFs and the importance of GF species in traditional plant use with the typical savanna vegetation of the country.

2.2.1 Diversity

All occurrences of GF species were extracted from the database of Schmidt *et al.* (2016) and subsequently double-checked for geographic errors using the CleanCoordinates function of the speciesgeocodeR package in R (R Core Team 2015, Zizka & Antonelli 2015, Töpel *et al.* 2017) using the default settings. Only non-problematic coordinates were used. If there were multiple records of a species with the same coordinates, only one record was retained. A total of 14,166 occurrence records of 260 species were used, no data was available for 47 GF species. The diversity patterns were visualized following the methodology of Schmidt *et al.* (2016). Diversity grids were calculated using the speciesgeocodeR package in R (Töpel *et al.* 2017, Zizka & Antonelli 2015).

In a second step all collection records of angiosperms from West Africa available at the 'Global Biodiversity Information Facility' (GBIF 2015) were downloaded (doi:10.15468/dl.uwugry) to illustrate the sampling situation and the rate of new species discovery in GFs. Records with no information on the collection year were discarded and the remaining records were cleaned for common geographic errors using the CleanCoordinates function of speciesgeocodeR (Töpel *et al.* 2017, Zizka & Antonelli 2015). The remaining species were scrubbed using the 'Taxonomic Name Resolution Service' (Boyle *et al.* 2013) and only species with a recognized accepted name were kept. Synonyms were merged under the accepted name. Only records from BFA were used. The proportion of species discovered for the first time in each decade were analysed for three species lists: 1) species occurring in GFs (149 species from the above described 307 GF species that were recorded in GBIF) 2) all species known to BFA not classified as GF species (1121 species), and 3) GF specialists, that is species that according to literature are mostly confined to GFs and do rarely occur in other habitats (24 species).

2.2.2 Taxonomic and Life-form Composition

Family identity and life-form following Raunkiaer (1934) for all species were retrieved from Thiombiano *et al.* (2013). Proportions of the major plant families and life-forms were compared between GF species and the total flora of BFA (2067 species from Thiombiano *et al.*, 2013).

2.2.3 Traditional Plant Use

Detailed information of traditional plant use was retrieved from Zizka *et al.* (2015). The importance of GF species in nine use categories was analysed: medicine, (human) nutrition, (animal) fodder, construction, tool crafting, firewood, religion/art, ornamental and veterinary. The proportion of species used in each category was compared between GF species and the total flora of BFA. Additionally, the number of categories in which the individual species were applied was compared. All analyses were performed with queries using MS Excel 2010.

2.2.4 Nomenclature

The nomenclature of all plant names mentioned in this thesis is according to the African Plants Database (version 3.4.0, 2012).

2.3 Distribution Modelling

Twenty particular typical gallery forest (GF) species with a good distribution record were selected from the list of 307 GF species for distribution modelling. The species number was reduced, to focus on species most closely linked to GFs and to ensure high data and model quality. The species were selected to include the most common elements of West African GFs as well as GF specialists and to cover a large taxonomic range.

2.3.1 Species Occurrence Data

A dataset of geographically unique occurrence records was compiled from four different sources (Table 1): i) The Herbarium Senckenbergianum, ii) field observation and rélevée data collected by I. Kirchmair and S. Oumarou and iii) data from the 'Global Diversity Information Facility' (GBIF 2015). Table 1 shows a detailed contribution of each source. In the case of GBIF, the repository was queried by species name and all West African countries and all georeferenced data points were downloaded. All data points were checked for geographic integrity using the speciesgeocodeR package in R (Zizka & Antonelli 2015, Töpel *et al.* 2017, Maldonado *et al.* 2015) and complementary by manual control.

Table 1: Sources for occurrence records used in distribution modelling of 20 typical gallery forest species. FR = Herbarium Senckenbergianum (Data from herbarium specimen in Frankfurt); Field data: herbarium specimen and field observation from rélevées; GBIF = Global Diversity Information Facility. Nomenclature according to African Plants Database (version 3.4.0, 2012).

Species	**Family**	**Total points**	**FR**	**Field data**	**GBIF**
Anogeissus leiocarpa	Combretaceae	112	16	22	74
Berlinia grandiflora	Fabaceae	86	0	5	81
Carapa procera	Meliaceae	62	1	2	59
Cola laurifolia	Malvaceae	12	2	10	0
Dialium guineense	Fabaceae	93	0	2	91
Diospyros mespiliformis	Ebenaceae	184	6	28	146
Elaeis guineensis	Arecaceae	63	0	5	58
Khaya senegalensis	Meliaceae	50	1	5	44
Manilkara obovata	Sapotaceae	91	4	3	83
Mitragyna inermis	Rubiaceae	136	5	28	103
Parinari congensis	Chrysobalanaceae	36	0	1	35
Paullinia pinnata	Sapindaceae	112	3	13	96
Pterocarpus santalinoides	Fabaceae	107	0	9	101
Saba senegalensis	Apocynaceae	77	4	5	68
Syzygium guineense	Myrtaceae	95	0	8	87
Uapaca togoensis	Phyllanthaceae	84	1	0	83
Uvaria chamae	Annonaceae	102	1	0	101
Vitex chrysocarpa	Lamiaceae	36	2	6	28
Vitex doniana	Lamiaceae	107	2	5	99
Xylopia longipetala	Annonaceae	13	2	5	6

The dataset was thus cleaned from problems common in public databases including non-numerical and invalid coordinates, plain zero coordinates, coordinates assigned to country capitals and country or province centroids. Additionally, data points with any other detected issues or with rounded coordinates (less than two decimal places) were removed from the dataset (see fig. 12A). Furthermore the occurrence points were spatially rarefied, allowing only one record per species in a radius of 20 km (see fig. 12B), to minimize the influence of clustered sampling as described in Brown (2014). A total of 1,658 data points with a mean of 83, a median of 89 and a minimum of 12 points per species were used for distribution modelling (fig. 12).

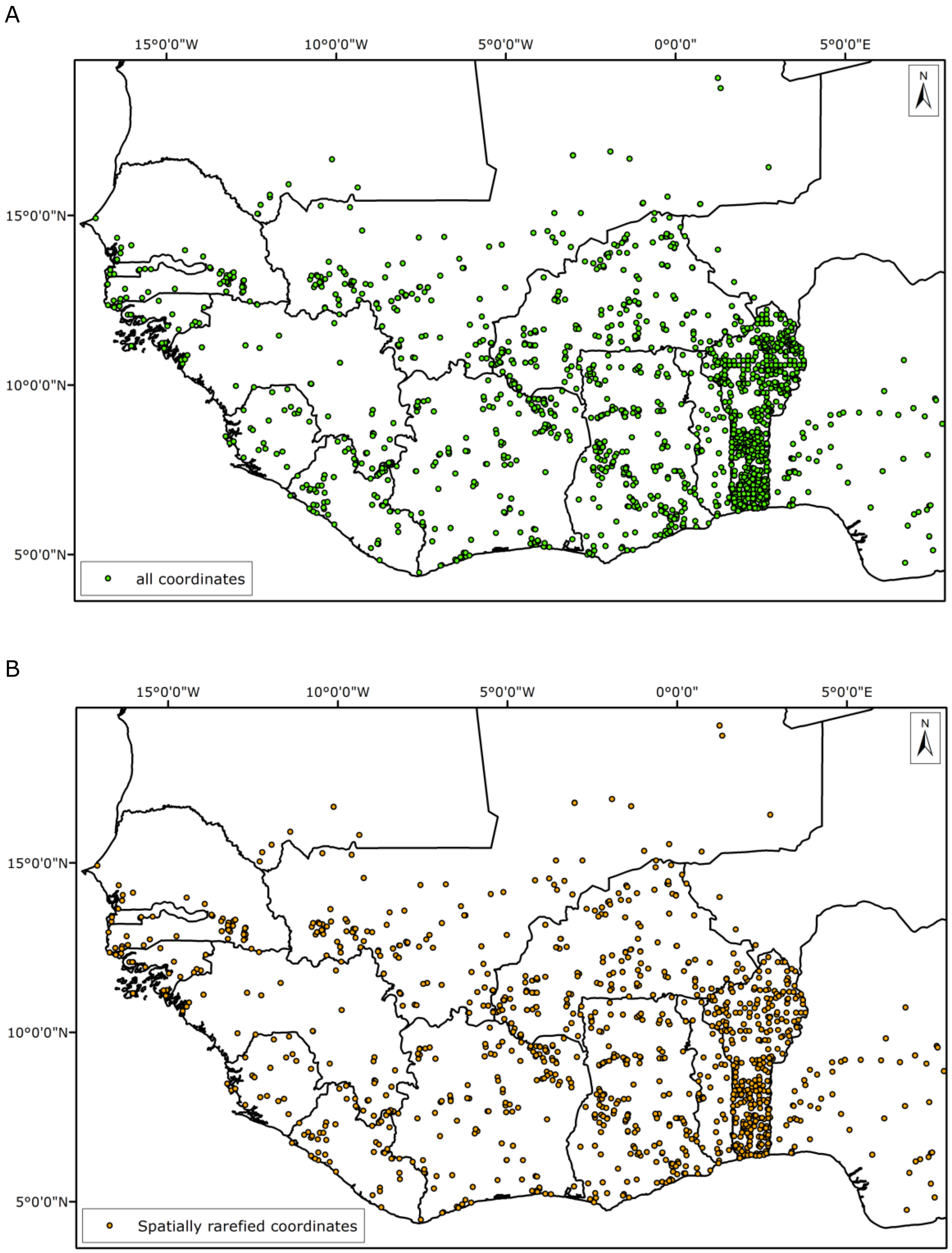

Fig. 12: Occurrence records for 20 characteristic gallery forest species. A) All records in the cleaned dataset, used for the conservation assessment; B) Spatially rarefied records (20 km radius), used for species distribution modelling.

2.3.2 Environmental Data

Three climate layers ('mean annual temperature', 'mean annual precipitation' and 'precipitation of the driest quarter') together with the 'minimum distance to the nearest major river' and the 'topographic wetness index' (TWI) were used as predictors to model species distributions at four different time slices: the Last Glacial Maximum (LGM, ca 19,000 years BP), the mid-Holocene (ca 5,000 years BP), present day and future (year 2085). For present day data was provided by AfriClim (Platts *et al.* 2014), for the future the AfriClim-Ensembles model based on the RCP 4.5 scenario was used. AfriClim provides statistically improved climate data based on WorldClim (Hijmans *et al.* 2005). For the mid-Holocene and LGM climate projections based on the 'Community Climate System Model' (CCSM4) as provided by WorldClim were used. The climate predictors were selected based on biological significance and to minimize correlations (Pearson index ≤ 0.7) as described by Brown (2014). To account for the specific characteristics of GF species and their natural association with wet, riverine habitats a predictor layer describing the 'minimum distance to the nearest major river' in meters and the 'topographic wetness index' (TWI) were used. The 'minimum distance to the nearest major river' for each gridcell was calculated with the distanceFromPoint function of the raster package in R, based on the inland water gazetteers for all West African countries, as provided at DIVA-GIS. The TWI combines local upslope area with slope to describe moisture availability in a given location and was developed by Beven & Kirkby (1979). Soil information was not included into the models because currently available soil data from SoilGrids or the Harmonized World Soil Database (Hengl *et al.* 2014, FAO/IIASA/ISRIC/ISSCAS/JRC 2012) were too coarse for the study area and were systematically missing data around rivers and in riverine areas.

2.3.3 Distribution Models

The distributions were modelled using the maximum entropy algorithm implemented in the program MaxEnt (Phillips *et al.* 2004, Phillips *et al.* 2006) with the SDMtoolbox in ArcGIS (Brown 2014) and the MaxEnt Java application (version 3.3.3k). The modelling procedure followed Brown (2014) and S. Phillips (2008) with the following modifications: 15 bootstrap replicates with a 25 random test percentage were run for each species, with 5000 iterations, hinge and threshold features were switched off. Response curves were created for each predictor variable and jackknifing was used to measure variable importance. The model output for each of the four times was converted to binary presence/absence data using an 'equal training sensitivity and specificity' threshold, to visualize the range shifts of GFs through time. These binary layers were then overlaid for all species to create maps of projected GF species diversity at all times. The fraction of grid cells with a projected presence for each species was used to calculate the area of (gallery) forest extension in West Africa through time. Differences in raster size were negligible due to the regional extent of the study and the proximity of the study area to the equator.

2.3.4 Conservation Assessment

The cleaned occurrence database from the distribution modelling was used for a data-driven automated conservation assessment of the 20 characteristic GF species. We calculated three indices to estimate the conservation status: the **'extent of occurrence' (EOO)**, which is the area of a convex hull around all species occurrences and indicates how widespread species are. The **'area of occupancy' (AOO)**, which is the accumulated area of all grid cells, in an equal-area grid with 4 km^2 cell size, in which a species actually occurred. The EOO and AOO evaluate two different features of extinction risk. The EOO indicates the range size of a species assuming that a high range size reduces the extinction risk. The AOO indicates the area actually populated by a species assuming that high population size reduces extinction risk. EOO and AOO are recommended indicators for species conservation status after IUCN criterion B (IUCN Standards and Petitions Subcommittee 2016). Additionally, the percentage of **potentially suitable habitat (PSH)** was calculated, which is the percentage of grid cells predicted as suitable habitat by the species distribution model. The Geospatial Conservation Assessment Tool (GeoCAT; Bachman *et al.* 2011) was used to calculate the EOO and AOO with all coordinates of the geographically cleaned dataset (fig. 12A). The PSH was calculated using the raster package in R (R Core Team 2015, Hijmans 2014).

2.4 Genetic Analyses

2.4.1 Study Species

Four ecologically distinct gallery forest (GF) species typical for Burkina Faso (BFA) were selected guided by the research questions for the genetic analyses (see section 1.5, III). The study species capture a maximum of the diversity of GF vegetation and thus, potentially, allow a robust generalization of the results to vegetation dynamics and genetic structure of GFs in general. They represent different plant families, different life-forms, different dispersal modes, different climatic niches, different abundance, and different degrees of dependence on GFs as habitat. Furthermore, all four have a large distribution range throughout BFA and occur in all four phytogeographical zones. *Anogeissus leiocarpa* and *Diospyros mespiliformis* are common and widespread in BFA and throughout West Africa, and occur abundantly in GFs, but are not GF specialists. *Paullinia pinnata* and *Pterocarpus santalinoides* are specialised on GFs and only occur in moist areas. The selection was made based on literature (Natta *et al.* 2002, Arbonnier 2002) and expert knowledge. The sample size for *Pterocarpus santalinoides* was lower than for the other species, and the samples were only taken from two river basins (West Coast and Volta) in the western part of BFA.

2.4.1.1 *Anogeissus leiocarpa* (DC.) Guill. & Perr.

Anogeissus leiocarpa belongs to the family Combretaceae. The family comprises 14 genera and 500 species of largely tropical trees, shrubs or lianas (Stevens 2001 onwards), often occurring in African savannas (Mabberley 1997). The stem age of the group was estimated to be about 90 million years (Sytsma *et al.* 2004). The genus *Anogeissus* is predominantly African, distributed from tropical regions to Arabia (Mabberley 1997). *A. leiocarpa* has an exceptional large ecological amplitude occurring in different habitats from dry savanna to forests in mid-altitudes from 1000-1800 m (African Plants Database version 3.4.0, 2012). In the study area *A. leiocarpa* is widespread and occurs in savannas, dry forests and GFs from the Sudano-Sahelian to the Sudano-Guinean zone, on compact and argillaceous soils (Ouédraogo *et al.* 2013). It tolerates temporary inundation. The dispersal mode is anemochory (Hovestadt *et al.* 1999). The species is widely used for traditional medicine, construction, veterinary purposes and also for alimentation (Thiombiano *et al.* 2013) and was found to be within the 12 most useful plants in BFA (Zizka *et al.* 2015b).

A. leiocarpa is a tree growing up to 15-30 m with a slender and dense crown, often drooping branches. The trunk can reach up to 70 cm in diameter. The fibrous bark with fine scales is grey to blackish (old trees). The leaves are opposite or subopposite, light green to ashen, elliptic to oval (blade: 2-8 x 1-4 cm). The inflorescence is globose with 10-20 cm in diameter, arises axillary or terminal and sits at the end of a peduncle of 5-25 mm length. The flowers are yellow-greenish or orange-brownish and 5-6 mm in diameter. The florescence begins at the end of the dry season or the beginning of the rainfalls, shortly after the foliation. The infructescence is globose and scaly. The fruits are yellowish trapezoidal samaras and 4-7 x 6-10 mm in size (Hutchinson & Dalziel 1954, Berhaut 1971, Arbonnier 2002).

Fig. 13: Habit and morphology of *Anogeissus leiocarpa*. A) Typical habit; B) Branching structure; C) Leaf structure and positioning; D) and E) Flowers in conspicuous heads; F) Fruits. Copyright pictures A, D, E and F Marco Schmidt, retrieved from 'African Plants – A Photo Guide' (Dressler *et al.* 2014).

2.4.1.2 *Diospyros mespiliformis* Hochst. ex A. DC.

Diospyros mespiliformis belongs to the family Ebenaceae. The family comprises four genera and approximately 550 species of predominantly trees (or shrubs) (Stevens 2001 onwards, Judd *et al.* 2002). The family is pantropically distributed and the crown-group was estimated to be about 54 million years old (Turner *et al.* 2013). The genus *Diospyros* is the most species-rich genus of the family with about 475 species, many of them of commercial importance as food or timber plants (Mabberley 1997). *D. mespiliformis* is widely spread throughout the African savanna belt and occurs in habitats such as GFs, on termite mounds and rocky hills, generally on profound and well drained soils (Arbonnier 2002, Kirchmair *et al.* 2012). The dispersal mode is zoochory, by birds (Wickens 1976) and different mammals (Hovestadt *et al.* 1999, Wickens 1976), such as flying foxes (Djossa *et al.* 2008) and baboons (Lieberman *et al.* 1979, Kunz & Linsenmair 2008). The species was ranked the third-most important used plant in BFA (Zizka *et al.* 2015b) and is widely used for medicine, alimentation, firewood and construction (Thiombiano *et al.* 2013).

D. mespiliformis is a 12-30 m tall tree with a dense and rounded crown. The trunk is straight and cylindrical and can reach over one meter in diameter. The bark is grey to black, muricate with fine rectangular scales. The leaves are alternate, dark green, oblong to elliptic (blade: 7-16 x 3-7 cm). The species is dioecious. The male inflorescence is a 2-3 cm long cyme that arises axillary and is composed of 3-9 flowers. Female flowers are isolated and arise axillary. The florescence is in the second half of the dry season. The fruits are 20-25 mm long ovoid drupes. They are yellow at maturity; the base is covered with a persistent calyx (Hutchinson & Dalziel 1954, Berhaut 1971, Arbonnier 2002).

Fig. 14: Habit and morphology of *Diospyros mespiliformis.* A) Branching pattern; B) Leaf structure and position; C) Flowers and D), E) and F) Fruits. Copyright for pictures A and E by Marco Schmidt, for pictures C and F by Philippe Birnbaum. Retrieved from 'African Plants – A Photo Guide' (Dressler *et al.* 2014).

2.4.1.3 *Paullinia pinnata* L.

Paullinia pinnata belongs to the family Sapindaceae (the lychee and rambutan family). The family comprises 140 genera and approximately 1630 species of mainly tropical or subtropical trees, shrubs and lianas (Stevens 2001 onwards, Judd *et al.* 2002). The crown age of the family is still debated and was estimated between 116-98 or 55-36 million years (Buerki *et al.* 2011, Quirk *et al.* 2012, Bell *et al.* 2010, Wikström *et al.* 2001). The genus *Paullinia* is one of the most species-rich genera of the family with about 150 species (Judd *et al.* 2002). The genus has its distribution focus in tropical America with only *P. pinnata* occurring in Africa (Mabberley 1997). Most species of the genus are lianas climbing with tendrils and many of them are known to contain pharmacologically active compounds such as caffeine and theobromine (Mabberley 1997). Some species are of commercial importance (Judd *et al.* 2002). *Paullinia pinnata* is widely distributed throughout tropical and subtropical Africa. In the study area, the habitats of *P. pinnata* are groves and GFs in the Sudanian and the Guinean zone on well drained soils. The dispersal mode is zoochory by birds (Hovestadt *et al.* 1999, Wickens 1976) and mammals (Wickens 1976), maybe also autochory (Senbeta *et al.* 2005). Different plant parts are used in traditional medicine and the fruits are edible (Thiombiano *et al.* 2013).

P. pinnata is a woody liana with tendrils with a sleek to coarse brown bark. The branches have four clearly visible grooves. The leaves are alternate and imparipinnate with five leaflets with a winged rhachis. The leaflets are oblong to oval (blade: 3-10 x 2-5 cm). They are glabrous and weakly and irregularly dentate. The inflorescence is a compact raceme that sits at the end of a long peduncle (up to 10 cm long), carrying 1 or 2 opposite twines. The white flowers (2-3 mm in diameter) with yellow spots emerge at the end of the dry season and in the rainy season. The florescence is in the dry season. The fruits are coned ligneous capsules that are more or less triangular. They are red at maturity with a farinaceous aril (Hutchinson & Dalziel 1954, Berhaut 1971, Arbonnier 2002).

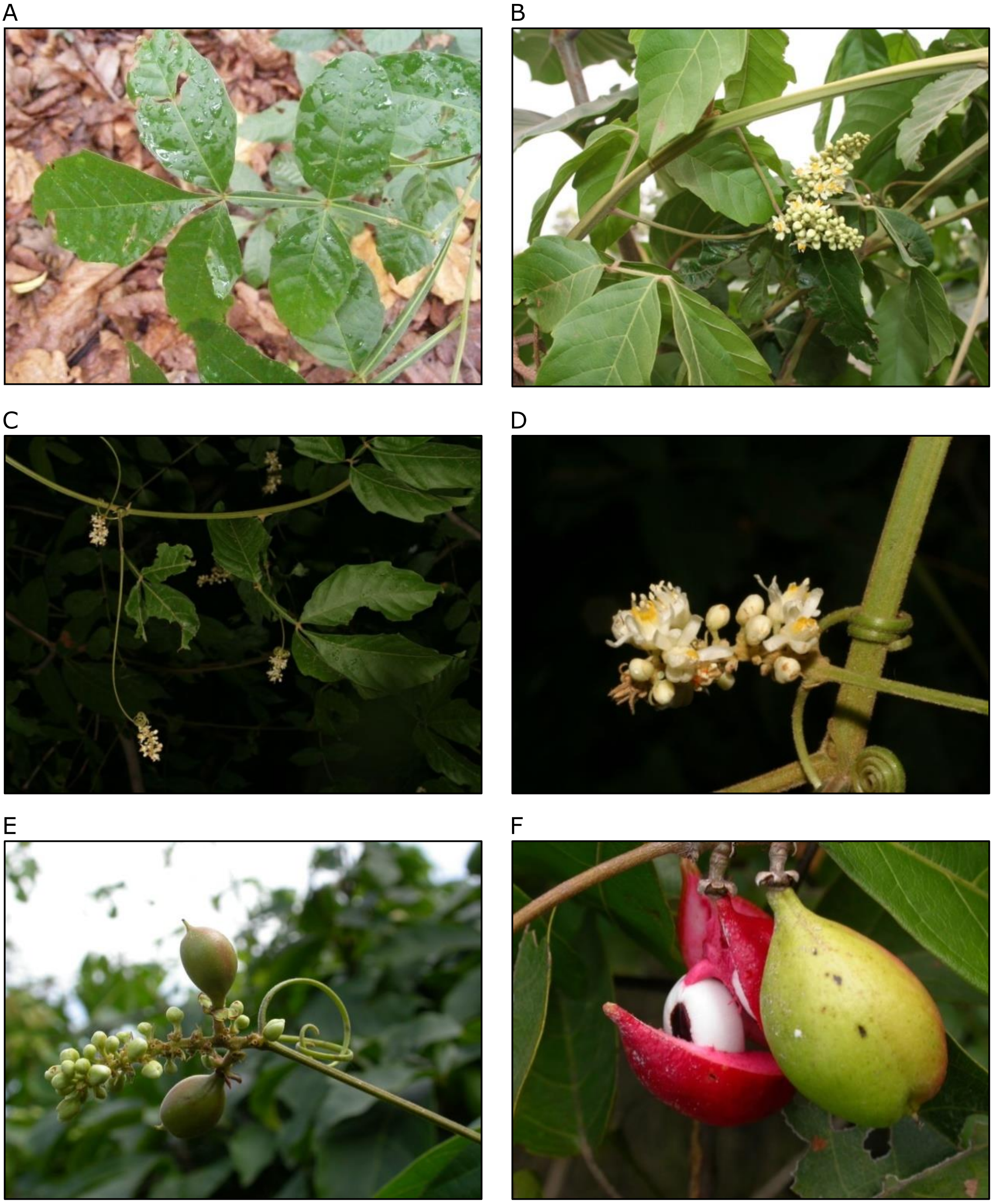

Fig. 15: Habit and morphology of *Paullinia pinnata*. A) Leaf structure and position; B) and C) Climbing habit with inflorescences; D) Inflorescence with open flowers; E) Infructescence; F) Fruits with conspicuous red aril. Copyright for pictures B, D and F by Marco Schmidt, and for pictures C and E by Philippe Birnbaum. Retrieved from 'African Plants – A Photo Guide' (Dressler *et al.* 2014).

2.4.1.4 *Pterocarpus santalinoides* L'Hér. ex DC.

Pterocarpus santalinoides belongs to the family Fabaceae. The family is the third most species-rich family worldwide and comprises 745 genera and about 20,000 species. The family is cosmopolitan and includes all growth forms, from trees to annual herbs (Stevens 2001 onwards). The Fabaceae are known for their symbiosis with nitrogen-fixing bacteria which enables the plants to use atmospheric nitrogen. The crown age of this group is still debated and is estimated to be between 68 and 56 million years (Bell *et al.* 2010, Wikström *et al.* 2001, Wikström *et al.* 2004, Bruneau *et al.* 2008, Lavin *et al.* 2005). The genus *Pterocarpus* is a tropical genus with 21 species (Mabberley 1997). *P. santalinoides* is a West African species occurring in mixed deciduous forest and flooded savanna, as well as on lake and lagoon sides and riverbanks (African Plants Database (version 3.4.0), 2012). In the study area habitats of *P. santalinoides* are riverbanks with sabulous or humid soils in the Sudano-Guinean and Guinean zone. This species is probably dispersed hydrochorous as the fruits have the ability to float (Arbonnier, 2002; Hutchinson & Dalziel, 1954-1972). In BFA the species is used for timber, human nutrition, animal fodder, traditional medicine and as a colorant (Thiombiano *et al.* 2013).

P. santalinoides is a 9-15 m high tree with a dense crown, long and often drooping branches. The species is usually evergreen, but in some situations briefly deciduous. The trunk is short and up to 50 cm in diameter. The bark is grey-brown with fine scales. The glabrous leaves are alternate, 15-25 cm long and imparipinnate with 2-5 pairs of alternate leaflets and a larger terminal leaflet. The leaflets are elliptic (blade: 5-13 x 3-6 cm). The 8-20 cm long inflorescence is an elongated raceme that sits axillary. The flowers are bright yellow to orange and 12-15 mm long. The florescence is in the dry season, generally at the beginning of foliation. The fruits are ovoid to globose, encircled by a small wing and 3-6 cm x 2-4 cm in size. They are beige to light brown at maturity (Hutchinson & Dalziel 1954, Berhaut 1971, Arbonnier 2002).

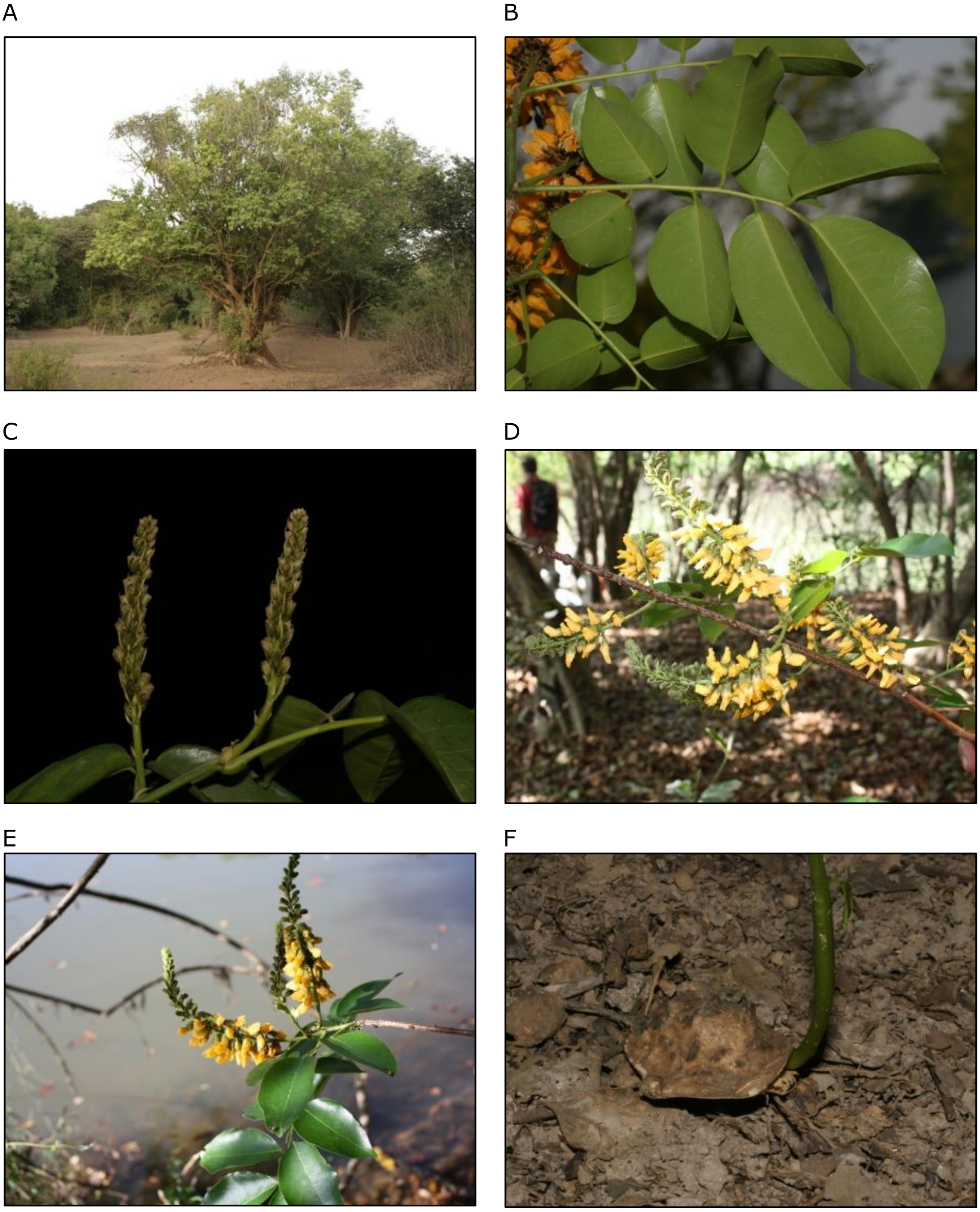

Fig. 16: Habit and morphology of *Pterocarpus santalinoides*. A) Typical habit; B) Leaf structure; C) Inflorescences before anthesis; D) and E) Inflorescences in flower; F) Germinating seedling. Copyright for pictures A, B, C and F by Philippe Birnbaum, for pictures D and E by Marco Schmidt. Retrieved from 'African Plants – A Photo Guide' (Dressler *et al.* 2014).

2.4.2 Tissue Sampling

A total of 245 tissue samples from 56 locations (fig. 11) were used to analyse the genetic population structure in all four study species (see annex 9.1 for a detailed list of samples). Up to three samples of the same species were used per site (fig. 11), assuming them to be replicates of the same population. Samples were collected along two 200 m transects parallel to the riverbed, close to the riverside on both sides of the river. If there were less than three individuals of a species at a site, samples from as many individuals as possible were collected. For every individual GPS coordinates were taken, a tissue sample in silica gel or CTAB buffer and a herbarium specimen were collected. Additional tissue samples collected by Dr. M. Schmidt, Dr. T. Janßen and others in October/November 2008 and Prof. S. Porembski in September/October 2010 were also included in the analyses. The total number of samples was chosen to balance between the need for replication and the logistic constraints of a national scaled study. All tissue samples collected during the field campaign were processed in the Grunelius-Möllgaard-Laboratory at the Senckenberg Research Institute in Frankfurt between 2009 and 2012.

2.4.3 DNA extraction

Samples collected in silica gel were grinded in a mix mill (Retsch®, Mixer Mill MM 200) at a frequency of 25 Hz for 2 minutes in 2 ml screw cap tubes with ceramic beads. Samples collected in CTAB buffer were frozen in liquid nitrogen and then grinded with a mortar and pestle; in both cases approximately 1.5 cm² leaf-tissue was used. The pulverised material was immediately transferred to the extraction buffer and the DNA was extracted using the 'QIAGEN DNeasy Plant Kit'. Extractions followed the manufacturer's protocol with the following modifications: in step 2 10 µl Proteinase K (20mg/ml) and 30 µl 2-Mercaptoethanol were added and the mix was incubated for 24 hours at 42°C. This enhanced the DNA yield significantly (see annex 9.3 for a detailed extraction protocol).

2.4.4 AFLP Identification

Amplified fragment-length polymorphism (AFLP) is a DNA fingerprinting technique, which is based on the PCR amplification of restriction fragments of genomic DNA (Vos *et al.* 1995). Differences in the genomic DNA caused by various genetic mechanisms, such as mutations and recombination, cause changes in the cutting sites of restriction enzymes leading to differences in fragment length when the genomes of different individuals are treated with the same set of restriction enzymes. The AFLP technique (hereafter called AFLPs) uses these differences in fragment length to evaluate the relation of two or multiple individuals by scoring the absence or presence of each fragment. AFLPs allow a scan of the whole genome without prior knowledge of DNA sequences. The high resolution of AFLPs enables investigating relationships on an individual level. Additionally, AFLPs have several advantages over other methods used on a population level: they have proven to be reliable, robust and highly reproducible and allow for a large sample size due to their relative low cost per sample (Meudt & Clarke 2007, Vos *et al.* 1995, Savelkoul *et al.* 1999, Jones *et al.* 1997). At the same time, the used markers are widely spread over the genome, allowing the evaluation of genome wide variations. AFLPs do only test for the presence or absence of a genetic fragment and do not inform about allelic states.

Figure 17 illustrates the workflow of a standard AFLP procedure. In this study AFLP reactions were conducted in the Grunelius-Möllgaard-Laboratory at the Senckenberg Research Institute in Frankfurt following the standard manufacturer protocol (DNeasy® Plant Mini Kit) with the following modifications: Genomic DNA was digested using the two restriction endonucleases MseI und HindIII, the latter one was used instead of the commonly used EcoR1 to reduce star-activity (Wei *et al.* 2008). The restriction enzymes differ in cutting sequence: MseI is a frequent cutter with a four base recognition site; HindIII is a rare cutter with a six base recognition site. Three different types of fragments (MseI-MseI, MseI-HindIII, HindIII-HindIII) with 'sticky ends' were generated during the digestion (step 1 in fig. 17). Subsequently, two adapter sequences (MseI and HindIII) were ligated to the sticky ends, to serve as binding sites for the pre-selective primers. The pre-selective primers carry one selective base extending into the sequence of the fragments which limited the amount of fragments that was amplified in step 2 (fig. 17) to sequences complementary to the primer. Three pre-selective primers were used: HindIII-A, MseI-A and MseI-C. To increase the stringency of the PCRs a touchdown PCR was conducted, i.e. the temperature decreased with every cycle. In the third step of the procedure (fig. 17), the selective PCR, primers with three selective bases were used to target the final sequences. A set of 51 primer combinations was tested with two test datasets of eight individual samples per species for the best amplification results and most adequate detection of genetic variation. These test-samples were picked to include pairs of samples from four distant geographic locations. The combination of supposedly very closely related and relatively distantly related individuals allowed optimising the primer resolution for both cases (see annex 9.2 for all primer combinations tested). Based on the results of this test a set of primers was chosen for the final analysis of each species (8-9 primer pairs; see annex 9.2). The three HindIII primers (HindIII-ACA, HindIII-AAC, HindIII-AGC) were labelled with different fluorescent dyes. The last step of the AFLP procedure (step 4 in fig. 17), a capillary electrophoresis of the fluorescence labelled fragments (Meudt & Clarke 2007), was performed in the laboratory of the Senckenberg Biodiversity and Climate Research Center in Frankfurt. The PCR amplification followed a standard protocol (see annex 9.3).

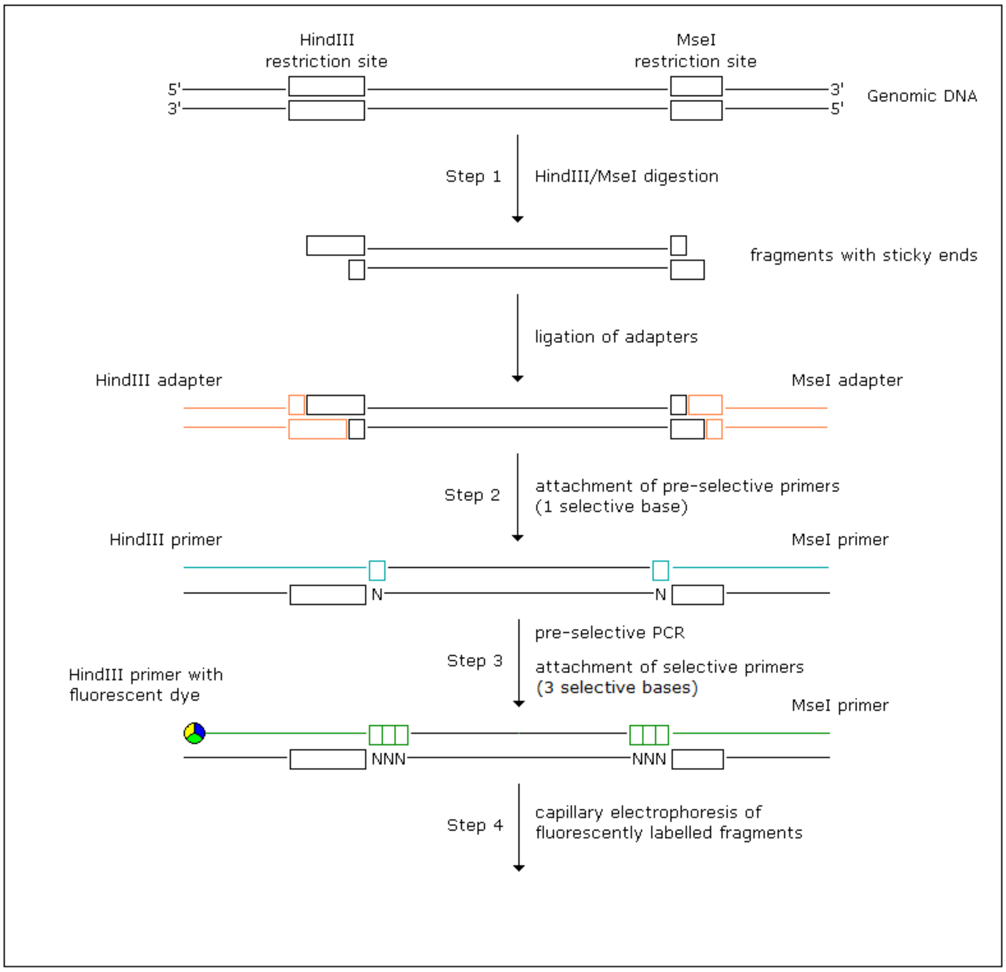

Fig. 17: AFLP workflow (modified after Meudt & Clarke 2007) showing all steps from genomic DNA to fluorescence labelled AFLP fragments.

The program *GeneMarker* (Softgenetics, version 1.71) was used to analyse the electropherograms of the AFLP data. Fragments were scored with a detection threshold set to 1000 rfu. Problematic peak regions were subsequently edited manually in a panel, because the automated scoring algorithm of the program proved to be too inaccurate on the data of this study. Only fragments between 100 and 450 bp length were scored to minimize the effect of size homoplasy of very short fragments (less than 100 bp) (Vekemans *et al.* 2002, Althoff *et al.* 2007) and to avoid problems with the complete amplification for long fragments above 400 bp. Subsequently, a second peak detection, with threshold of 100 rfu was run, every bin was scored manually and peaks were added or deleted if necessary. In a bin (ideally 0.8 bp wide), at least one peak had to be higher than 1000 rfu otherwise the entire bin was deleted. After the manual scoring all peaks in a bin that had less than 10 % of the fluorescence of the second highest peak was erased. In cases where there was only one dominant peak, all peaks less than 10 % of the dominant were deleted. However, peaks below the 10 % threshold were kept if they occurred in all electropherograms and their intensity decreased gradually. A binary presence-absence matrix was used for all subsequent analyses.

2.4.5 Genetic Population Structure

As a first step a 'Principal Coordinates Analysis' (PCoA) was conducted with *GeneAlEx* (version 6, Peakall & Smouse 2006) to test if there is any pattern in the genetic data of the four study species. PCoA is a multidimensional scaling technique that plots the major patterns within a multivariate dataset according to the (dis)similarities between individuals. PCoA takes a distance matrix as input. The genetic population structure was inferred with three different approaches using the programs *STRUCTURE* (version 2.3.3, Pritchard *et al.* 2000), *BAPS* (Corander *et al.* 2003) and *SplitsTree* (Huson & Bryant 2006). *STRUCTURE* is a software tool to investigate genetic structure in population level samples. It can be used for "demonstrating the presence of population structure, identifying distinct genetic populations, assigning individuals to populations, and identifying migrants and admixed individuals" (Pritchard *et al.* 2010, page 3). The method is based on model-based clustering as presented by Pritchard *et al.* (2000) and extended by Falush *et al.* (2003) and Falush *et al.* (2007). *STRUCTURE* was used to test the most likely number of populations (K) for all four study species ($1 \leq K \leq 10$) and to assign individuals to populations. Admixed membership was allowed with membership coefficient summing to 1, but for further analyses the individuals were assigned to the population with the highest membership coefficient. As AFLPs are dominant markers, the AFLP data was coded with the observed allele (1 or 0) and the missing allele (-9) as recommended in the *STRUCTURE* documentation (Pritchard *et al.* 2010). Burn-in was set to 100,000 and the number of MCMC repetitions after burn-in was 100,000 as well. Five MCMCs were run for each *K*. The *STRUCTURE* results were evaluated using the *STRUCTURE Harvester* software (Earl & VonHoldt 2012) and visualized using *STRUCTURE PLOT* (Ramasamy *et al.* 2014) and *DISTRUCT* (Rosenberg 2004). *BAPS* (Bayesian Analysis of Population Structure) is a program to analyse genetic population structure in relation to an explicit spatial model. Here, version 6.0 was used to test the genetic clustering in the four study species in relation to the river basins. We tested this for the number of populations K = 1 ≤ *K* ≤ 10. *SplitsTree* is a program for rapid analysis and visualisation of relationships between samples of genetic data based on tree or network methods. Version 4.13.1 was used to visualize genetic structure within the four study species as a network with the Dice coefficient as a distance measure (Dice 1945).

2.4.6 Species-tree diffusion models

A species-tree diffusion model approach following Nylinder *et al.* (2014) as implemented in BEAST (version 1.7, Drummond *et al.* 2012) was used to locate the phylogeographic origin of the AFLP genotypes and to reconstruct the phylogeographic history of the study species. With this approach the AFLP matrix was used to build a tree of sample relations, based on the collection location of each sample, to infer a possible location for each ancestral node in the tree, including uncertainty. See Nylinder *et al.* (2014) for a detailed description of the method and Nylinder (2013) for a tutorial on the implementation. The phylogenetic trees were inferred with a simple binary model with equal state frequencies, under a yule tree prior, a strict clock model and a simple species-tree diffusion model without environmental matrix. A random jitter of 0.001 was added in case of identical coordinates. A large number of tree-inference and geographic models were tested, but more complex models failed to converge or showed poor mixing. The MCMC was run for five million generations and burn-in was set to 500,000. The trees with the highest clade credibility were annotated using TreeAnnotator (Drummond *et al.* 2012) and visualized in geographic space using SPREAD (Bielejec *et al.* 2011) and Google Earth. The .xml files for the BEAST runs and the annotated trees can be found in the Zenodo repository (doi:10.5281/zenodo.376190).

2.4.7 Correlations between Genetic Population Structure and Environment

A paired Mantel test in *GenAlEx* (version 6, Peakall & Smouse 2006) was used to test the effect of spatial auto-correlation and isolation by distance. To test the correlation of genetic population structure (as found in the genetic analysis in *STRUCTURE* and *BAPS*) with environmental drivers, five soil variables relevant for plant growth were extracted from SoilGrids at 1 km resolution for the study area (Hengl *et al.* 2014) and 19 climate variables at 30'' resolution (ca. 1km) were extracted from Africlim (Platts *et al.* 2014). In a first analysis the *STRUCTURE* and *BAPS* populations were treated as independent groups and significant variance between them was tested for all environmental factors using an analysis of variance in R (R Core Team 2015).

2.5 Data Accessibility

The raw data used in this study are attached as supplement to this thesis or are available in the Zenodo repository (doi: 10.5281/zenodo.376190). The geographic location data collected in this study are available via the African vegetation database (M. Schmidt *et al.* 2010) and published as part of the distribution atlas of vascular plants in Burkina Faso (Schmidt *et al.* 2017). The AFLP data used for analyses of genetic population structure are available in the Zenodo repository (doi:10.5281/zenodo.376190) and additional tissue samples are stored in the silica/CTAB collection of the Herbarium Senckenbergianum in Frankfurt. Herbarium specimens are deposited in the Herbarium of the University of Ouagadougou (OUA) and the Herbarium Senckenbergianum (FR). The data used for the distribution modelling is available in the Zenodo repository together with detailed results of the distribution modelling (doi:10.5281/zenodo.376190).

3 Results

3.1 Diversity, Flora, and Plant Use in Gallery Forests

3.1.1 Diversity

Figure 18 shows the diversity of gallery forests (GFs) in Burkina Faso (BFA). The southwest and northeast of BFA emerged as centres of species richness (fig. 18B). The southwest of the country was particularly species-rich with more than 100 GF species in 2,500 square kilometres. The species richness of GF species correlated closely with sampling effort (fig. 18A). In general, the species number followed a latitudinal gradient with an increasing richness per grid cell from north to south (fig. 18D). For conservation purposes the diversity in political units (fig. 18C) is of particular interest. In BFA the southernmost provinces comprised by far the highest number of GF species. Species richness was highest in the provinces Comoé, Houet and Tapoa and lowest in the provinces Kourwéogo, Loroum, Zondoma and Bam.

The time of first recording of GF species showed a clear signature of pulses of collection effort in BFA (fig. 19). Two initial smaller periods of collection activity in the beginning of the century (1900-1910, 1930-1940) alternated with a decrease in collection activity during the decades of both World Wars. The time between 1960 and 1980 showed a steep increase in species discovery and similarly discovery increased again between 1990 and 2000. Non-GF species, GF species and GF specialists showed a very similar pattern, with the exception of the last decade (2000-2010), when first collections decreased for non-GF species and GF species, but increased for GF specialists, with 20 % of all first collections made in this time period. Note however, that the sample size for GF specialists was small (55 ssp.)

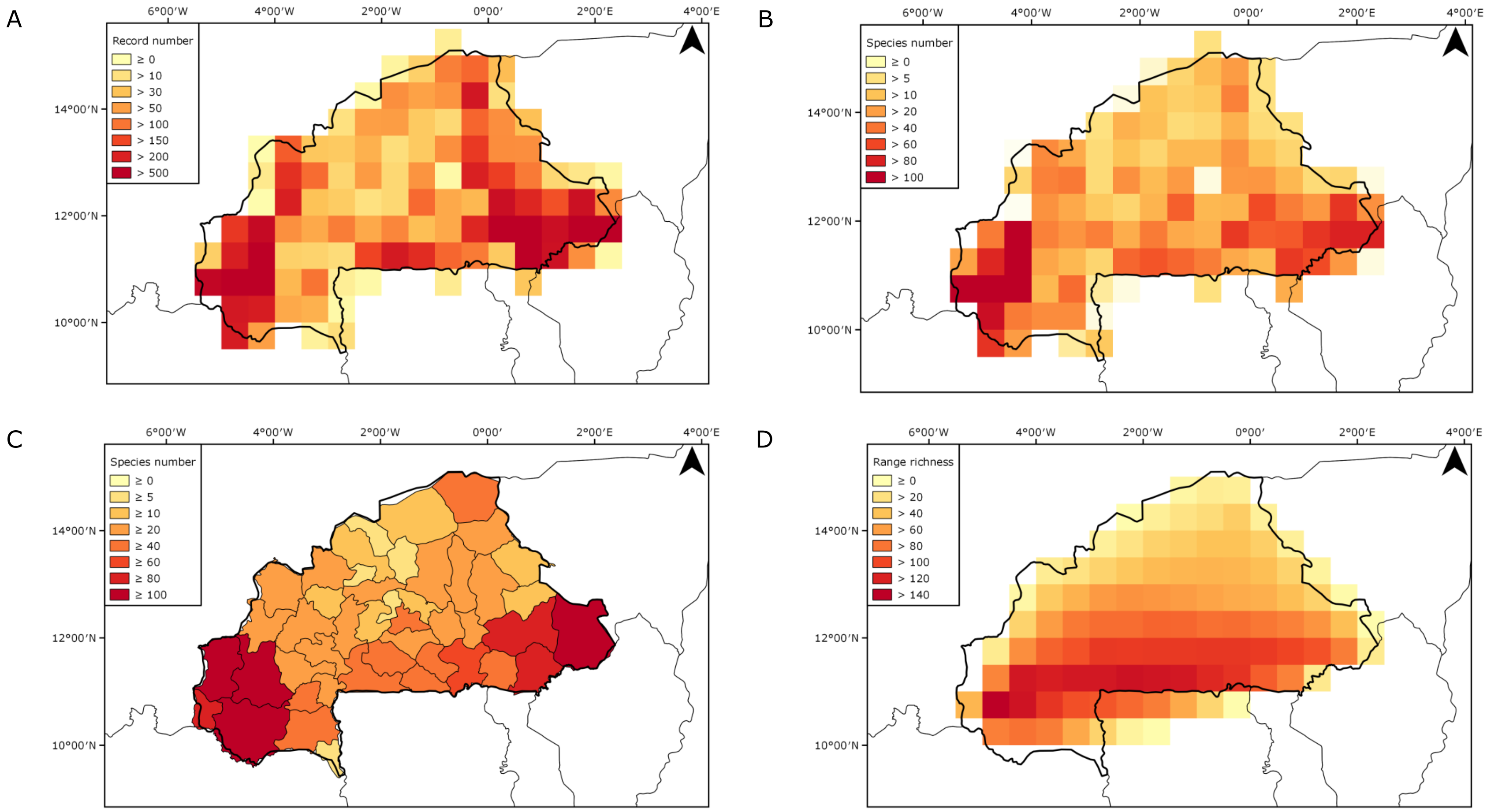

Fig. 18: Distribution of gallery forest species in Burkina Faso. A) Record number per grid cell; B) Species number per grid cell; C) Species number per province; D) Richness per grid cell based on species ranges calculated as convex hulls.

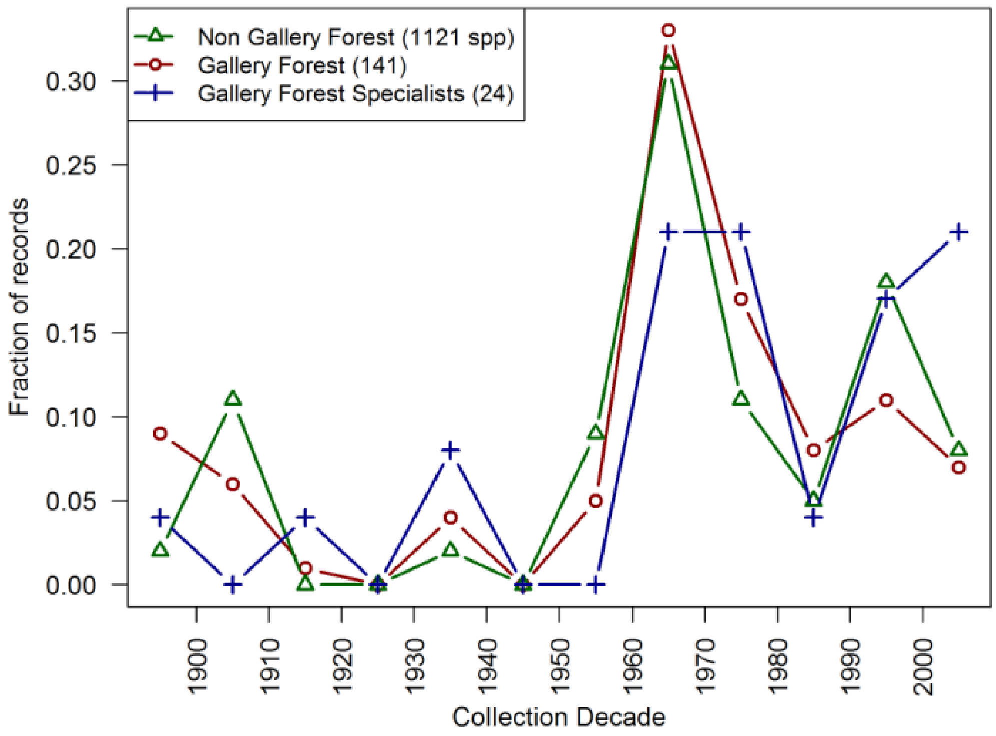

Fig. 19: Time of first collection of a species in Burkina Faso from 1900-2010. Collection date from GBIF (see section 2.2.1). Data cleaned with speciesgeocodeR (Zizka & Antonelli 2015, Töpel *et al.* 2017). First increase around the 1970s, then intensified collecting during the last decade especially in GFs.

3.1.2 Flora

The number of plant species differed significantly among the different habitats of BFA. Figure 20 shows the percentage of the total flora known to BFA occurring in seven major habitats. Most species either occurred in savannas (35 %) or forests (24 %) or in both habitats (13 %). GFs were the most species-rich of the four azonal habitat types included in the study (GFs, ruderal, aquatic and inselbergs). 307 species in BFA occured in GFs, which equals 15 % of the total flora. Note however, that habitat information was only available for 1087 species.

The species-rich GF flora differed in structural and taxonomical composition from the total flora of BFA. The structural difference results from differences in the species richness of different growth forms (fig. 21): while therophytes were the most species-rich growth form (33 %) in BFA, GFs mostly comprised phanerophytes (56 %). Therophytes were still the second-most species-rich group in GFs, but comprising less than one-fourth of the number of phanerophytes species. Noteworthy, the liana-type growth form was clearly overrepresented in GFs with 10 % compared to 4 % in the national flora. The species number of medium-sized growth forms, notably hemicryptophytes, chamaephytes and geophytes was similar or slightly less species-rich in GFs compared to the national flora.

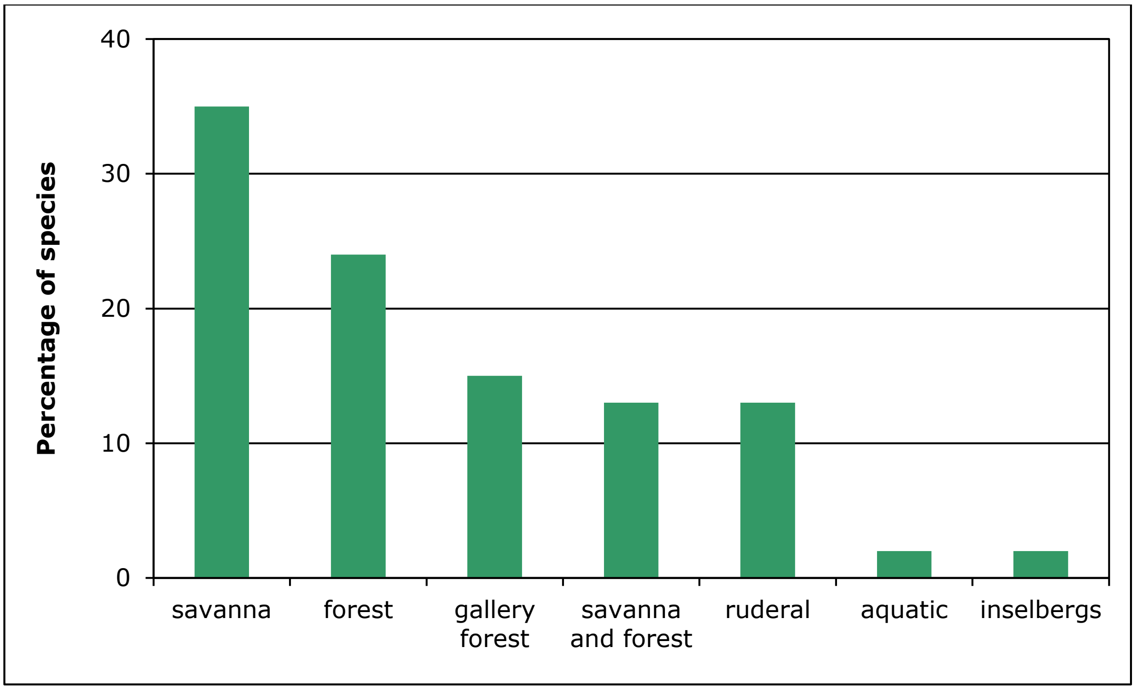

Fig. 20: Habitat preferences of plant species in Burkina Faso. The bars show the percentage of species with available habitat information (1087 species) in the major habitats. Species can occur in multiple habitats. GFs are the third species-rich habitat type in Burkina Faso, despite the fact that they only cover a small area in the country.

The GF flora was also particular in taxonomical composition. Figure 22 shows the eight most species-rich plant families in the national flora of BFA (fig. 22A) and in GFs (fig. 22B). Six families (Fabaceae, Poaceae, Rubiaceae, Cyperaceae, Apocynaceae and Euphorbiaceae) were listed in both rankings. Asteraceae and Malvaceae, which were within the eight most species-rich families in the total flora, were replaced by Acanthaceae and Moraceae in GFs. Furthermore, the plant families differed in their position between the two rankings. Plant families with predominant herbaceous species that were major contributors to the national diversity (Poaceae, Cyperaceae and Asteraceae) showed a reduced species richness in GFs (fig. 22C). In contrast Rubiaceae, Apocynaceae, Acanthaceae, Moraceae, Vitaceae and Phyllanthaceae were distinctly overrepresented in GFs. Particularly, families comprising mainly woody species and/or lianas or climbers (Rubiaceae, Moraceae, Apocynaceae and Vitaceae) showed relatively higher species richness in GFs.

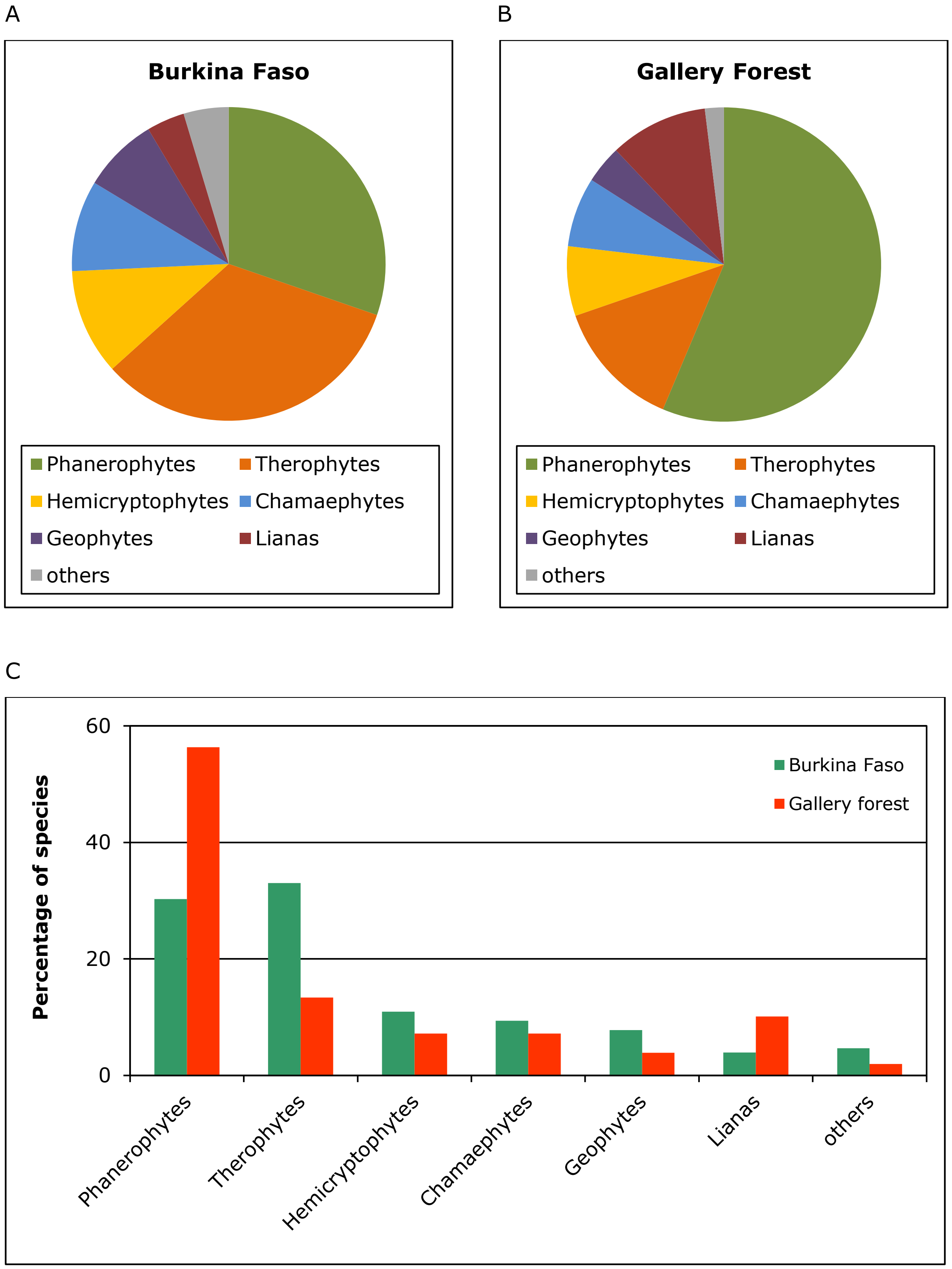

Fig. 21: Plant life-forms in Burkina Faso and Burkinian gallery forests. A) Percentage of life-forms in the total flora of BFA; B) Percentage of life-forms in the GF flora; C) Comparison of A) and B). GFs are an important habitat for phanerophytes and lianas. In contrast, therophytes and geophytes are underrepresented.

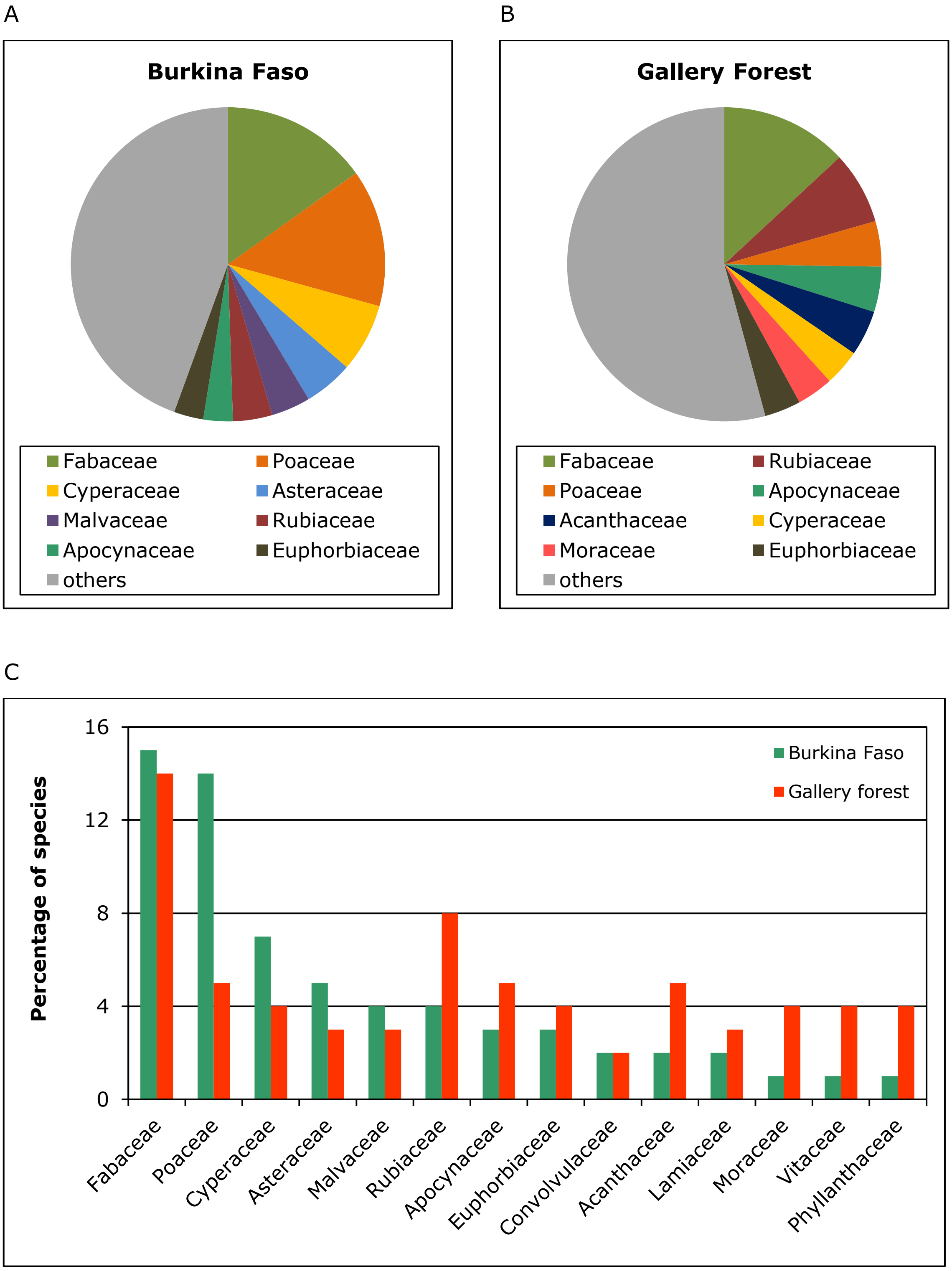

Fig. 22: The most species-rich plant families in Burkina Faso and Burkinian gallery forests. A) Total flora of BFA; B) Flora of Burkinian GFs; C) Comparison of A) and B). Rubiaceae, Acanthaceae and Moraceae are strongly overrepresented in GFs. In contrast, Poaceae and Cyperaceae are underrepresented.

3.1.3 Traditional Plant Use

The proportion of species with a known traditional use was higher in GFs (59 %) than in the total national flora of Burkina Faso (50 %). Additionally, the proportion of used species in GFs was higher in eight out of nine use categories (fig. 24). The difference was particularly striking for the use of plants in traditional medicine (TM). TM was the most important use category of GFs and the total flora, but a much higher proportion of species was used in GFs (55 % vs 36 %). Furthermore, considerably more plant species in GFs were used for construction (19 % vs 13 %), tool craft (18 % vs 11 %), firewood (14 % vs 9 %) and religion/art (14 % vs 5 %). The only plant use category with a higher proportion of used species outside GFs was fodder (15 % vs 19 %). In addition, species from GFs were also more commonly used for multiple purposes and for a higher number of purposes (fig. 23).

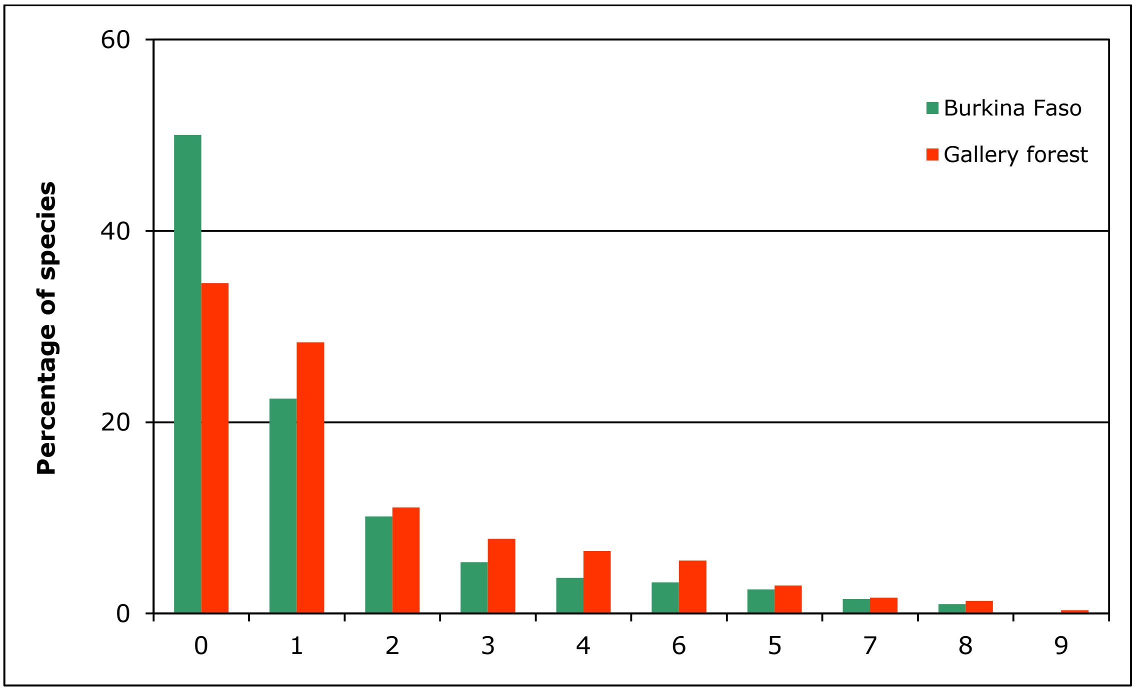

Fig. 23: Use of plant species in multiple categories. The bars show the percentage of species used in the respective number of categories (see fig. 24). The x-axis shows the number of categories. There were fewer species in GFs without any use. Additionally, plants from GFs were used in more categories, stressing the importance of these habitats for local human communities.

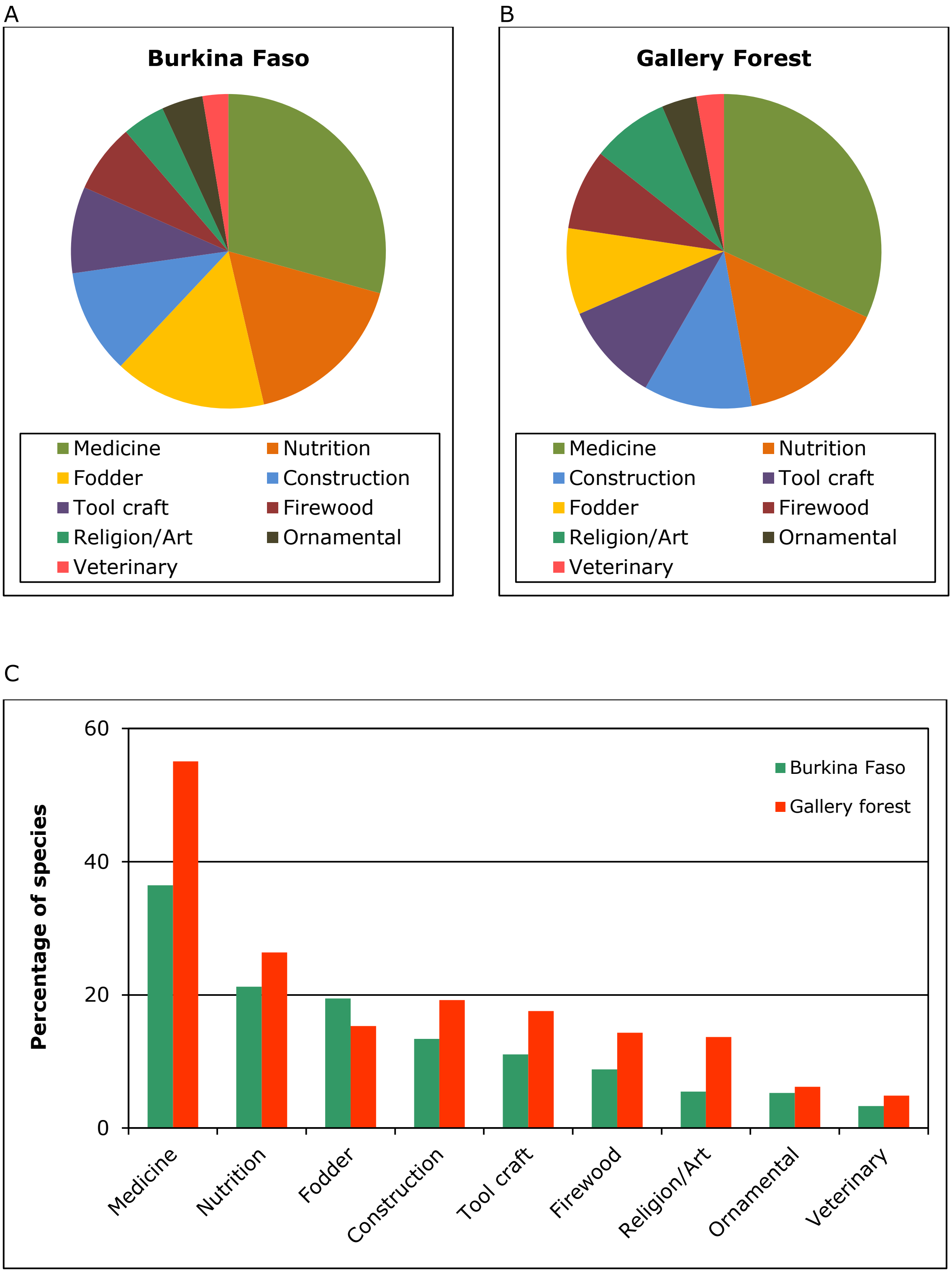

Fig. 24: Traditional use of plants from the flora of Burkina Faso and Burkinian gallery forests. A) Use of plants in nine different categories (Zizka *et al.* 2015b); B) Use of plants in nine different categories in Burkinian GFs; C) Comparison of A) and B). Generally, a higher proportion of the flora is used in GFs. Plants can be used in multiple categories.

3.2 Distribution Ranges of Gallery Forest Species

The species distribution models showed a strong response of the 20 study species to climatic conditions, and indicated largely different areas of 'potentially suitable habitat (PSH)' for gallery forest (GF) species among the 'Last Glacial Maximum' (LGM), the mid-Holocene, present time and the expected conditions in 2085.

Out of the large set of environmental factors tested, 'mean annual temperature (MAT)', 'mean annual precipitation (MAP)', 'precipitation of the driest quarter', 'topographic wetness index' and 'minimum distance to the nearest major river' were the best predictors for the distribution of the study species. The contribution of the predictors varied considerably among species. 'Mean annual precipitation' was generally the predictor with the highest explanatory power over all species (predictor contribution, mean = 37 % ± 9, median = 39 %) followed by 'mean annual temperature' (mean = 33 % ± 6, median = 32) and 'minimum distance to the next major river' (mean = 17 % ± 7, median = 15). The 'precipitation of the driest quarter' (mean = 9 % ± 6, median = 9 %) and the 'topographic wetness index' (mean = 5 % ± 3, median = 4 %) in general contributed less. General model performance was good, with a mean AUC of 0.84 ± 0.03. The contribution of 'minimum distance to the next major river' was particularly high for *Cola laurifolia* (36.1 %), *Xylopia longipetala* (32.0 %), *Parinari congensis* (21.5 %) and *Anogeissus leiocarpa* (21.1 %), and particularly low for *Dialium guineense* (9.7 %), *Berlinia grandflora* (10.4 %), *Uvaria chamae* (10.5 %) and *Carapa procera* (11.1 %).

In general, the PSH for GF species increased through time from the LGM until present time (ANOVA: F = 16.28, $p < 0.001$) (see fig. 25). This pattern was observed both for total area and also for area normalized per species (to account for different developments of single species). A 'Turkey Honest Significant Difference test' revealed that PSH was significantly lower during the LGM than at all other times ($p_{HOL-LGM} < 0.05$, $p_{PRE-LGM} < 0.01$, $p_{FUT-LGM} < 0.001$) and significantly higher in the future (2085) than at all other times ($p_{FUT-LGM} < 0.001$, $p_{FUT-HOL} < 0.001$, $p_{FUT-PRE} < 0.01$), the difference between the mid-Holocene and present day was not statistically significant.

For 16 out of 20 study species the PSH was smaller during the LGM compared to present day conditions and for nine species more than 98 % smaller compared to present conditions. The mean loss in PSH under LGM conditions compared to present day was 64 %. For *Anogeissus leiocarpa*, *Cola laurifolia*, *Khaya senegalensis* and *Parinari congensis* no PSH area was projected during the LGM.

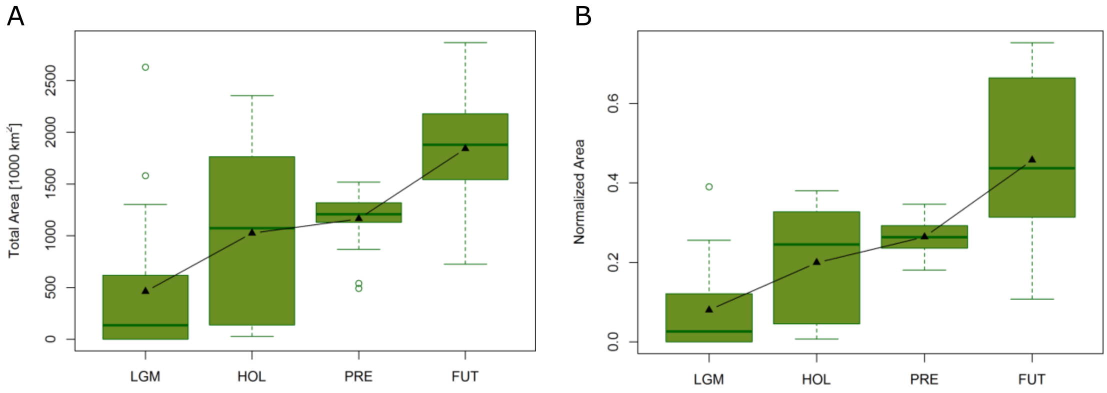

Fig. 25: Area of GFs through time. A) Total area; B) Fraction of the area over all time points. LGM = Last Glacial Maximum, HOL = Mid-Holocene, PRE = present conditions, FUT = projections for 2085. PSH increases through time.

The PSH for *Carapa procera*, *Dialium guineense*, *Uapaca togoensis* and *Uvaria chamae* was higher compared to today. The change in PSH between the LGM and present day was significantly positively correlated with the contribution of the 'precipitation of the driest quarter' layer (linear model, $p < 0.05$), marginally significantly correlated with the contribution of the 'minimum distance to the next major river' layer ($p > 0.05$) and significantly negatively correlated with MAT ($p < 0.01$). That is, the more influential 'precipitation of the driest quarter' and 'distance to the nearest river layer', the more PSH did a species gain since the LGM, and the more influencial MAT, the lesser area.

For 17 out of 20 species the PSH was projected to increase under future climate conditions. The average change in PSH compared to today was 70 %. The projected increase was highest in *Vitex chrysocarpa* (218 %), *Cola laurifolia* (197 %) and *Xylopia longipetala* (170 %). For *Carapa procera* (-40 %), *Uapaca togoensis* (-35 %) and *Uvaria chamae* (-17 %) a loss in PSHt was projected. The change in PSH between present day and future climate conditions was negatively correlated with the importance of the MAP layer in the model ($p > 0.05$), significantly positively correlated with the importance of the MAT layer ($p < 0.001$) and the importance of the 'minimum distance to the next major river' layer ($p < 0.01$), and significantly negatively correlated with the precipitation of the driest quarter ($p < 0.05$).

A projection of the modelled species distribution into geographical space showed potential centres of GF diversity through time. Figure 26 shows a species richness map from the projections of the 20 species. Individual projections for all study species are shown in the supplementary material available in the Zenodo repository (doi:10.5281/zenodo.376190). During the LGM, only relatively small areas in the southern and western parts of West Africa were suitable for GF species, and no area was suitable for all study species (fig. 26A). The suitable area increased drastically during the climatic optimum in the mid-Holocene, when the centre of GF species diversity was found in central West Africa, and habitat suitable for multiple species extended up to 15° north (fig. 26B). Under present climate conditions, slightly less area was found suitable for many GF species and the areas of highest potential diversity retracted southwards (fig. 26C). The projection for climate conditions in 2085 indicates a strong increase in suitable habitat for GF species and an increase in potential high diversity areas (fig. 26D). Through all times the southwestern tip of West Africa was projected with low potential diversity. The model stressed the importance of rivers for the distribution of GF species. The projected diversity was higher in proximity to large rivers (red bands in fig. 26 and fig. 27). This was in particular the case in Burkina Faso (BFA) (fig. 27). For 2085, the maximum increase in GF species in an area was +15, and the maximum decrease was -5 species.

The regional oscillation of PSH and potential GF species richness had consequences in the area that today comprises BFA, as this area is on the northern border of GF occurrence. There were no species with PSH in this area during the LGM. This suggests that no significant refugia for GF species were present at this time in this area (fig. 27A). The climatic shifts towards the mid-Holocene led to a strong increase in PSH in the area, even including large parts potentially suitable for all 20 species (fig. 27B). Present day climatic conditions led to a similar pattern with a slight southward shift of potentially species-rich areas (fig. 27C). The models predict a further increase in the area suitable for GFs under future climate conditions, including a slight expansion of the range of some species to the north (fig. 27D).

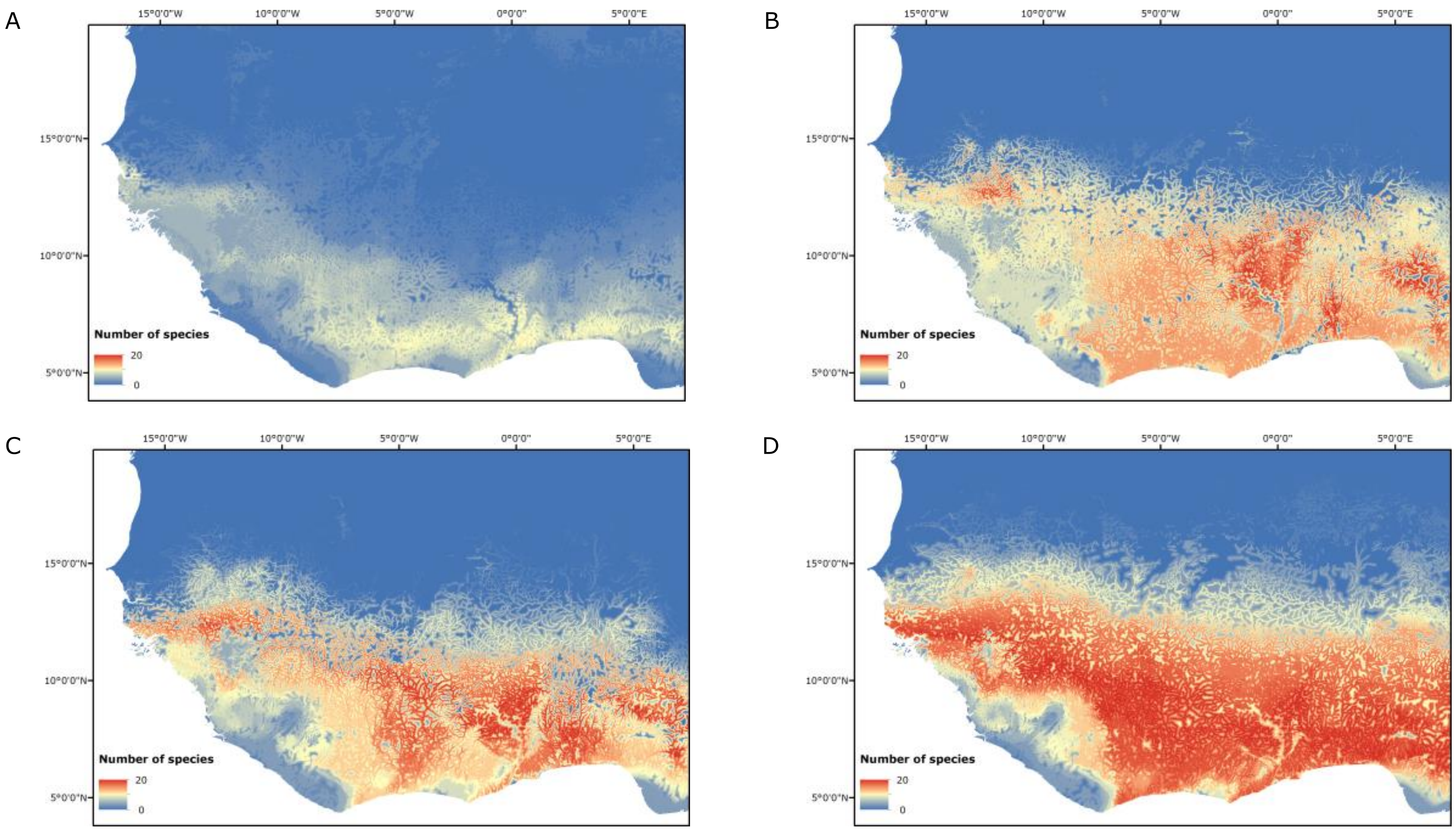

Fig. 26: Potential species richness and PSH for 20 GF species in West Africa. A) Last Glacial Maximum (19,000 years BP); B) Mid-Holocene (5,000 years BP); C) present day; D) future (2085). The areas of high potential diversity increase since the LGM. Areas of high species richness shift southwards between mid-Holocene and present day. Colours indicate the number of species with PSH.

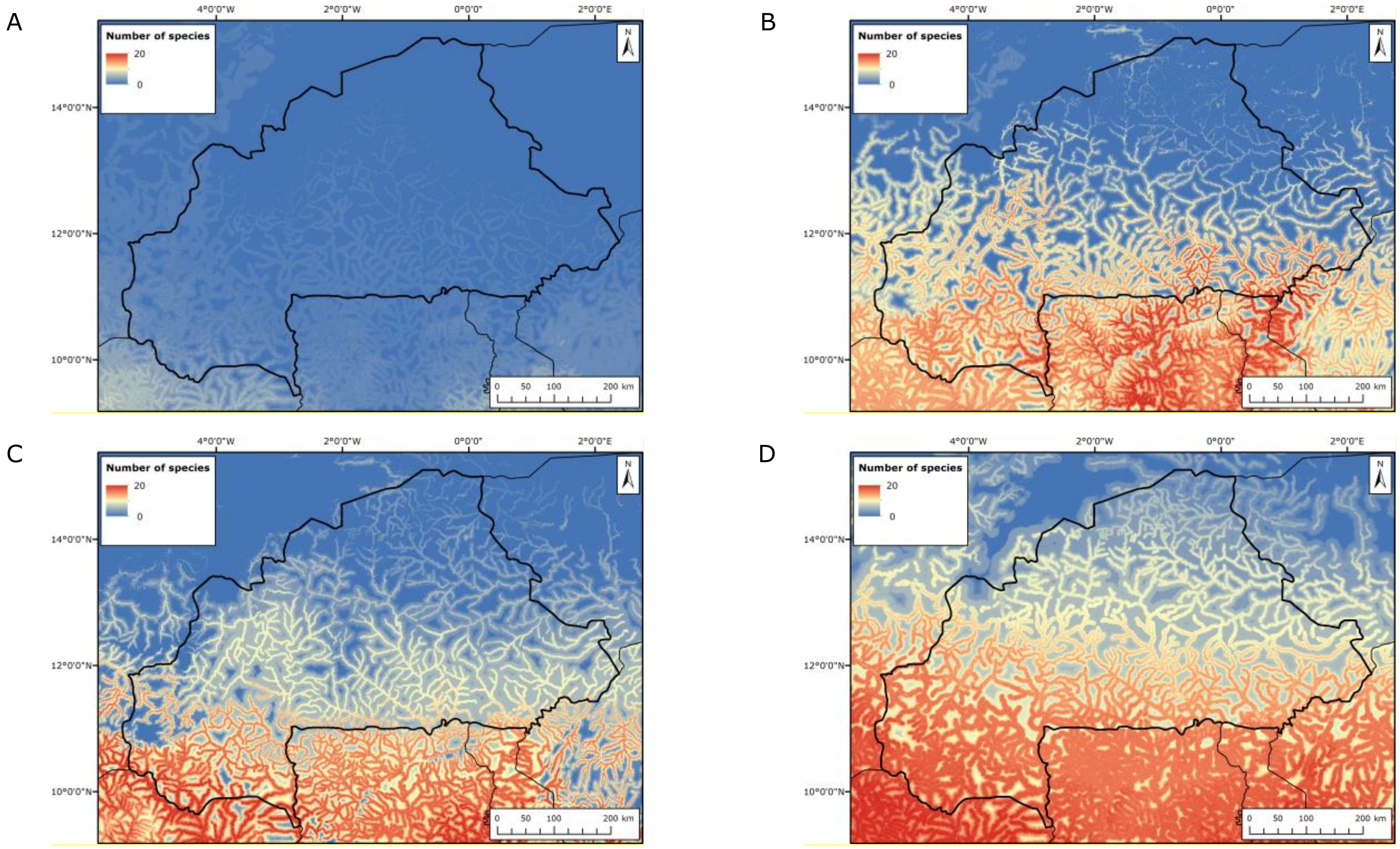

Fig. 27: Potential gallery forest species richness in Burkina Faso modelled for four different time periods. A) Last Glacial Maximum (19,000 years BP); B) Mid-Holocene (5,000 years BP); C) present day; D) future (2085). There were no PSH in the area under Pleistocene climatic conditions. Colours indicate the number of species predicted as percent in a grid cell.

The four study species whose genetic structure was investigated in more detail in this study differed in their projected response to climate variables.

The species distribution model for *Anogeissus leiocarpa* was mainly influenced by MAT (43 %), MAP (33 %) and 'minimum distance to the next major river' (21 %). No PSH for the species was projected during the LGM, but a 133 % increase of PSH area under future climate conditions. The PSH under present climate conditions ranges throughout West Africa, but is concentrated between 25° and 10° north, which corresponds with the northern limit of forest species distributions. Very little PSH was projected in the southern part of West Africa. A strong increase in habitat suitability was projected for the species across the entire distribution range under future climate conditions (fig. 28).

The projected spatial distribution of *Diospyros mespiliformis* was similar to *A. leiocarpa*. The model was mainly influenced by MAP (42 %), MAT (36 %) and 'minimum distance to the next major river' (18 %). Almost no PSH was projected during LGM conditions (-99.99 % compared to present day) and an 80 % increase of PSH under future conditions was projected. Under present day conditions the distribution range of *D. mespiliformis* stretches across West Africa, with the exception of the southwestern parts. A strong increase in PSH was projected throughout the distribution range under future conditions (fig. 29). The PSH for *A. leiocarpa* and *D. mespiliformis* differed slightly from the general picture of GF species (fig. 26) in that it is shifted northwards towards drier areas.

The distribution model for *Paullina pinnata* was mainly influenced by MAP (41 %), MAT (30 %) and 'precipitation of the driest quarter' (14 %). The influence of the 'minimum distance to the next major river' layer was smaller than for most other species (11 %). Compared to most other study species the reduction in PSH for *P. pinnata* was moderate, albeit still high (-71 %) and the increase under future conditions was close to average (55 %). The focus of PSH under current climate conditions is clearly towards southern West Africa, with a decrease in habitat suitablility northwards up to about 12° north. For *P. pinnata* potential refugia with suitable habitat under LGM conditions were found on the Atlantic coast in southern West Africa. Under future climate conditions the PSH increased throughout the entire distribution range, also shifting northwards up to about 14° north (fig. 30).

The species distribution model for *Pterocarpus santalinoides* was dominated by MAT (32 %) and MAP (28 %) but the influence of all variables was relatively balanced compared to most other species with similar distributions for 'minimum distance to the next major river' (15 %), 'precipitation of the driest quarter' (15 %) and 'topographic wetness index' (10 %). Similar as for *P. pinnata*, the changes of PSH at LGM conditions (-75 %) and the increase under future conditions (51 %) were close to average. The centre of PSH for *P. santalinoides* was along the Atlantic coast of West Africa. Potential refugia with PSH might have existed along the coast during LGM climate conditions. Under future conditions the PSH for *P. santalinoides* increases throughout the distribution range, but predominantly in southern West Africa (fig. 31).

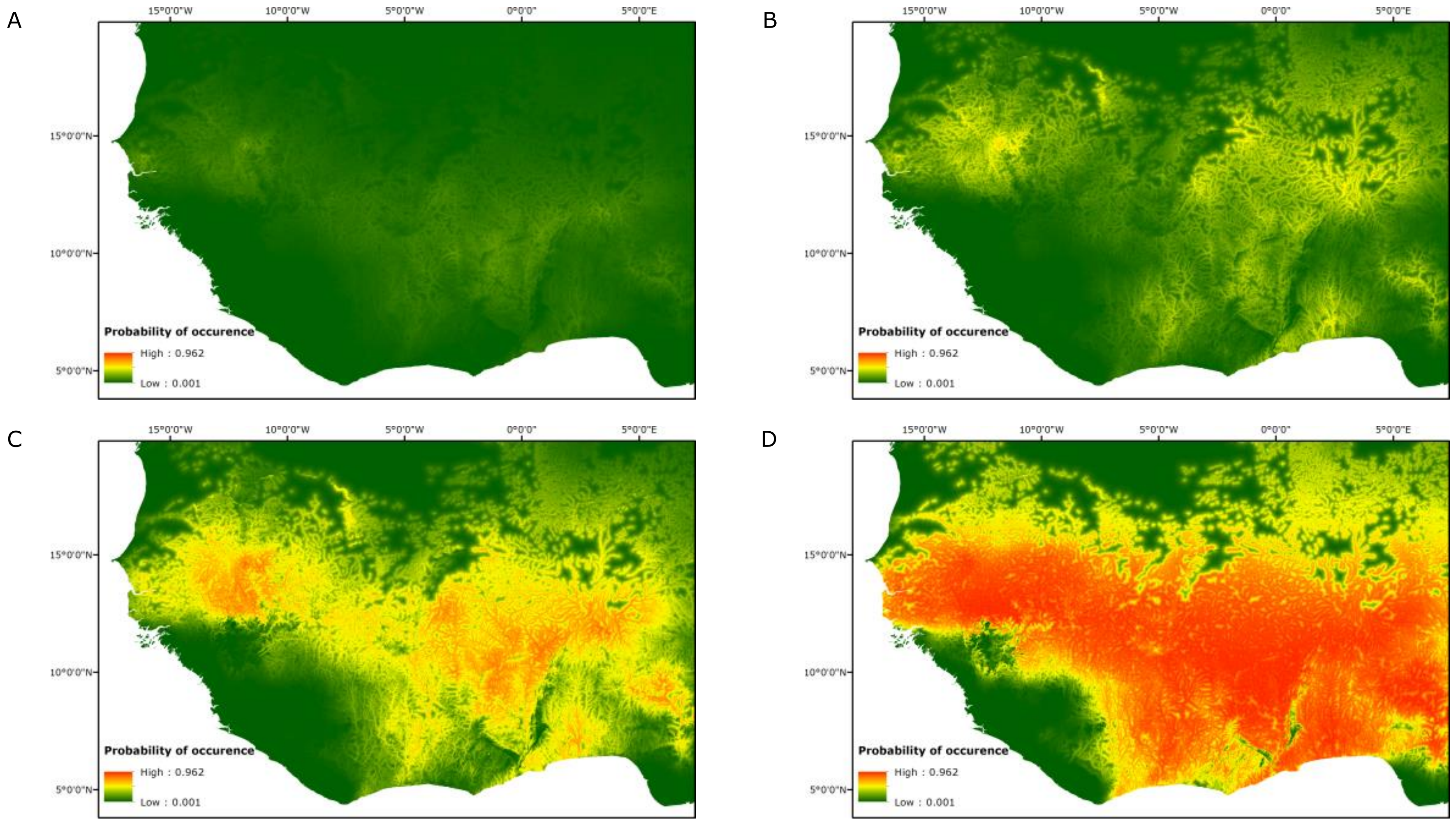

Fig. 28: Projected distribution of *Anogeissus leiocarpa.* A) Last Glacial Maximum (19,000 years BP); B) Mid-Holocene (5,000 years BP); C) present day; D) future (2085). Colours indicate potential habitat suitability. The PSH continuously increases since the LGM.

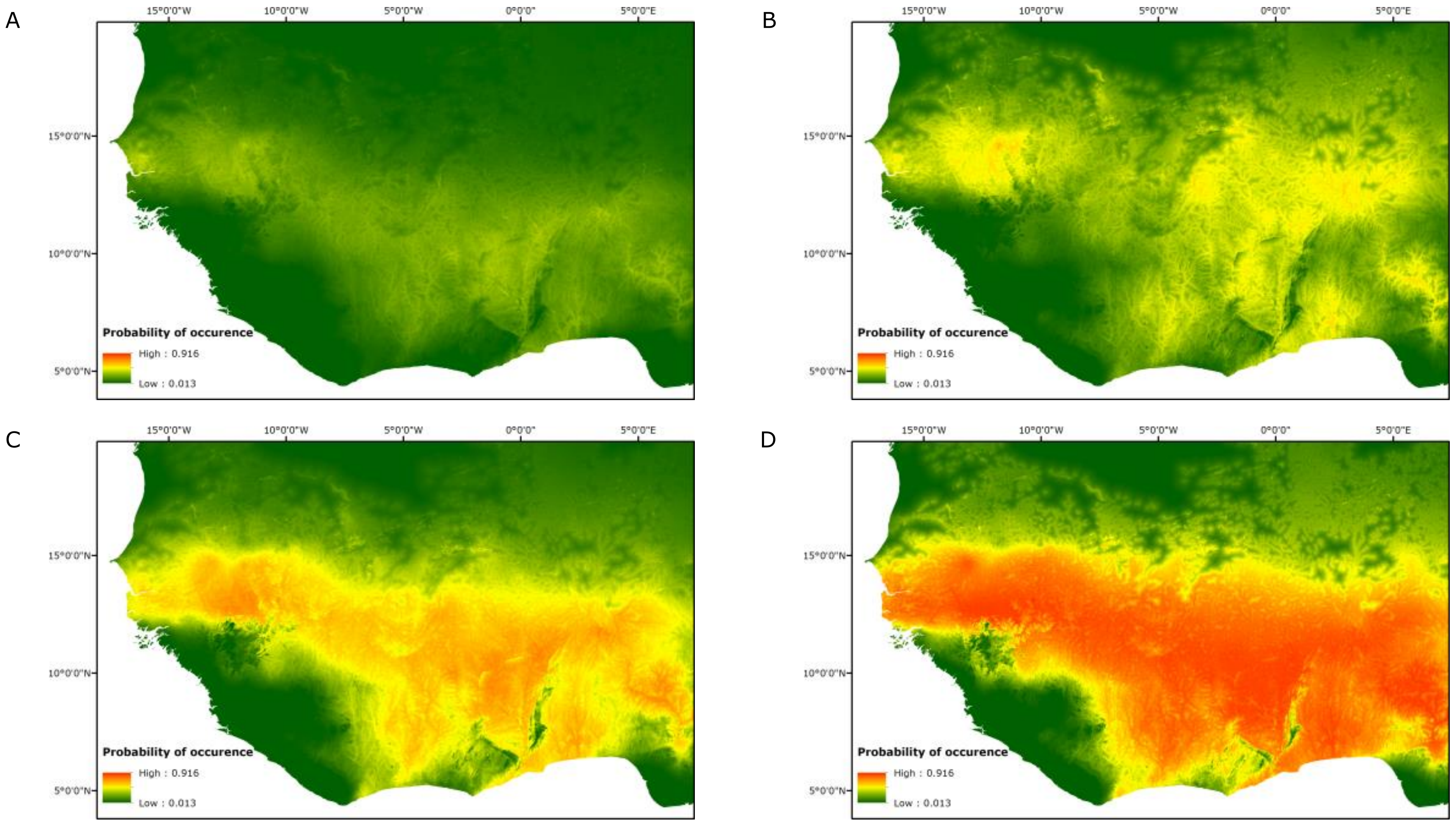

Fig. 29: Projected distribution of *Diospyros mespiliformis*. A) Last Glacial Maximum (19,000 years BP); B) Mid-Holocene (5,000 years BP); C) present day; D) future (2085). Colours indicate potential habitat suitability. The PSH continuously increases from the LGM.

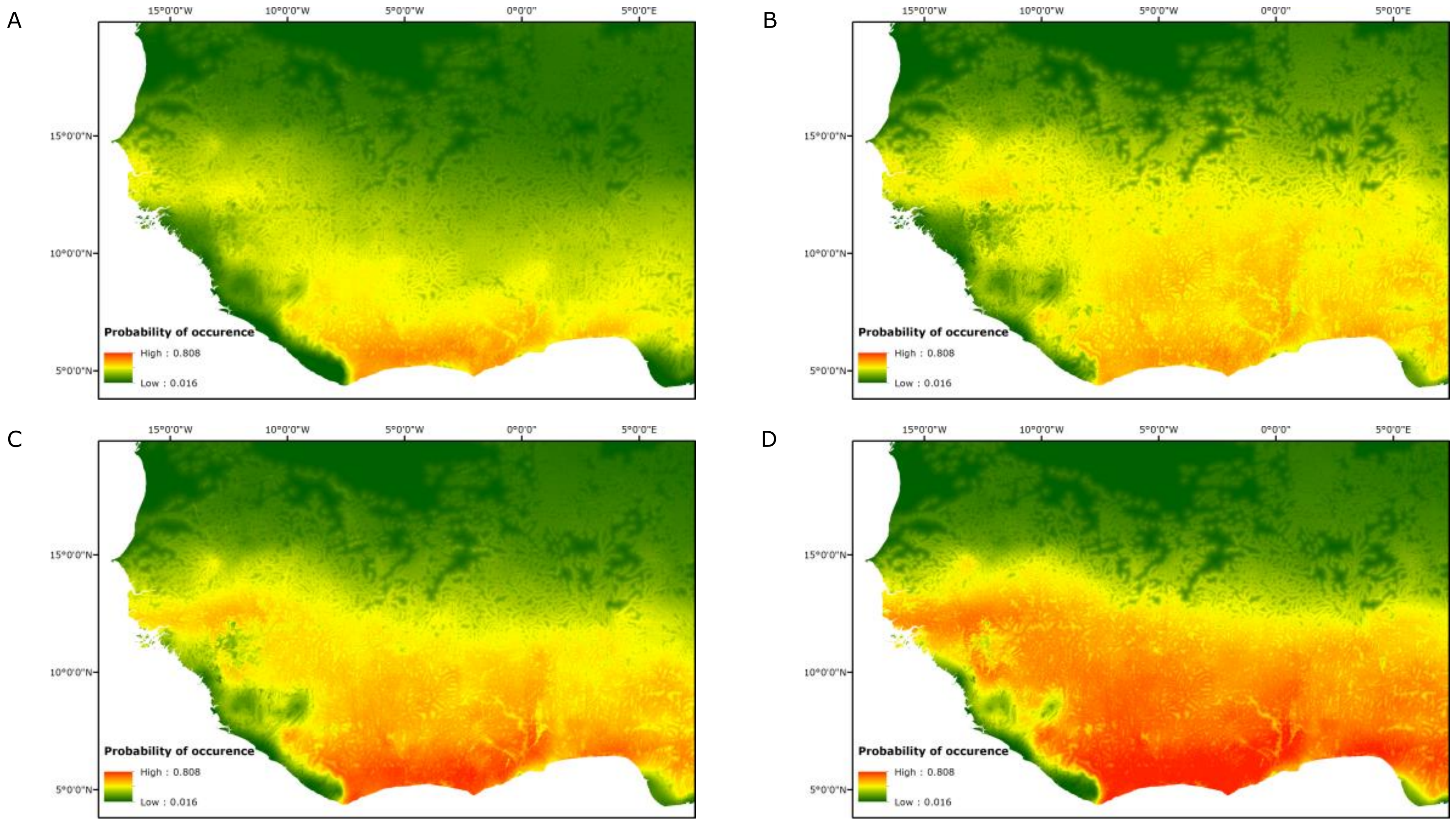

Fig. 30: Projected distribution of *Paullinia pinnata*. A) Last Glacial Maximum (19,000 years BP); B) Mid-Holocene (5,000 years BP); C) present day; D) future (2085). Colours indicate potential habitat suitability. The species had potential refugia in southern West Africa during the LGM and other glacial periods.

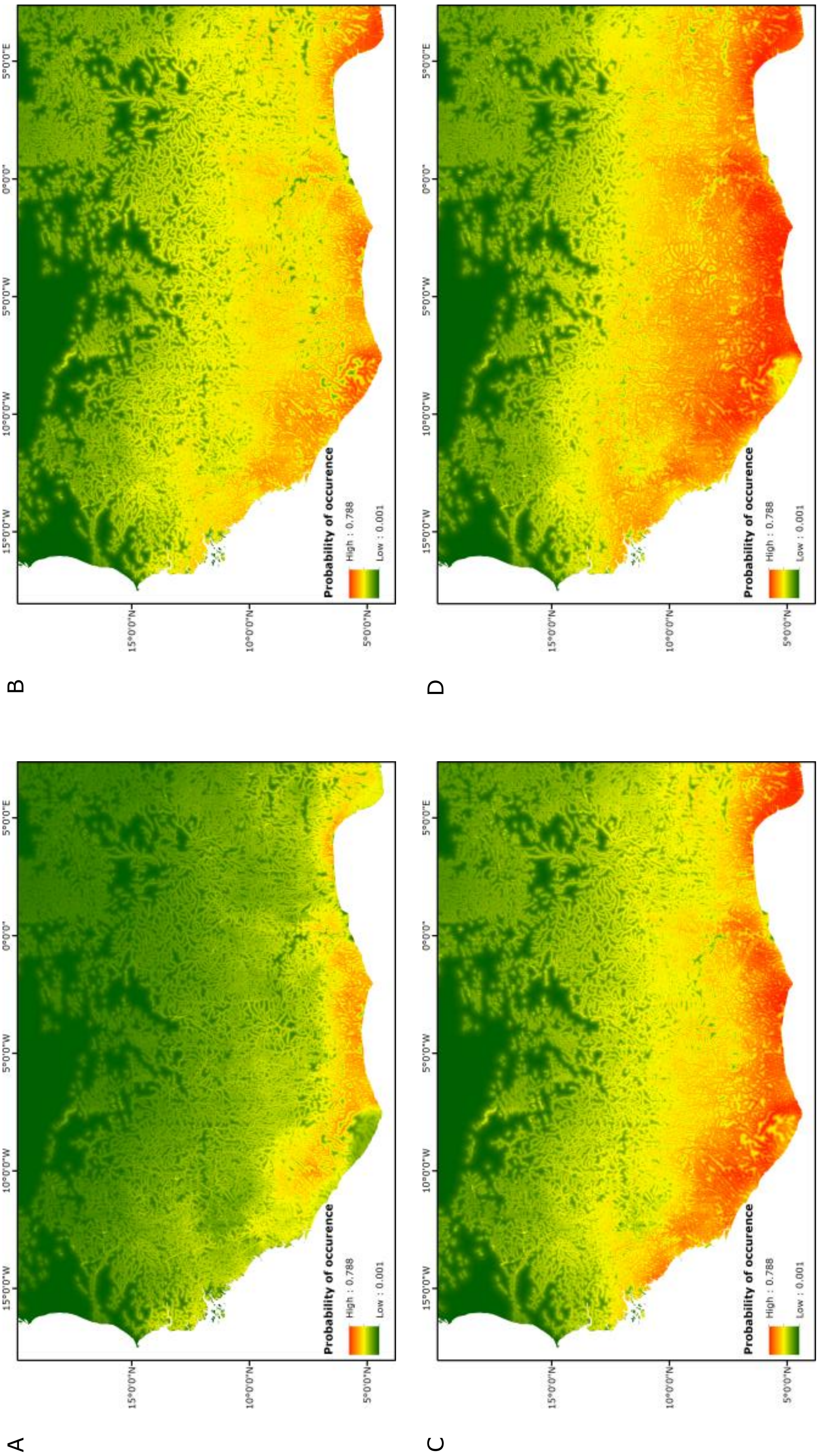

Fig. 31: Projected distribution of *Pterocarpus santalinoides*. A) Last Glacial Maximum (19,000 years BP); B) Mid-Holocene (5,000 years BP); C) present day; D) future (2085). Colours indicate potential habitat suitability. The species had potential refugia in southern West Africa during the LGM and other glacial periods.

3.2.1 Conservation Assessment

Table 2 shows 'extent of occurrence' (EOO), 'area of occupancy' (AOO) and the derived conservation assessment for 20 GF species. The assessment was based on a median number of 196 occurrence points (min: 23; max: 2070). In general, GF species are widespread throughout West Africa. The mean EOO was 1,620,750 km². The most widespread species were *Diospyros mespiliformis*, *Anogeissus leiocarpa,* and *Mitragyna inermis*, with an EOO of over 2 million km². The least widespread species were *Cola laurifolia* and *Xylopia longipetala*, with an EOO below 600,000 km². Due to the large range sizes the EOO conservation assessment was found to be 'least concern'. The mean AOO was 545 km². We found the highest AOO for *D. mespiliformis*, *M. inermis,* and *Uapaca togoensis*, with an AOO over 700 km². The lowest AOO were found for *C. laurifolia* and *X. longipetala* with an AOO below 100 km². The AOO based conservation assessment showed a somewhat more critical picture with a classification of the species as 'vulnerable' or 'endangered'.

Table 2: Conservation assessment of 20 GF species in West Africa. EOO: extent of occurrence, a measure for the range size of a species; OP: occurrence points; AOO: area of occupancy, a measure for the area actually populated by the species; LC: least concern; VU: vulnerable; EN: endangered. Nomenclature according to African Plants Database (version 3.4.0) (2012).

Species	OP	EOO [km²]	EOO category	AOO [km²]	AOO category
Anogeissus leiocarpa	262	2,418,000	LC	668	VU
Berlinia grandiflora	171	1,605,000	LC	488	EN
Carapa procera	109	1,116,000	LC	336	EN
Cola laurifolia	35	197,000	LC	80	EN
Dialium guineense	228	1,956,000	LC	548	VU
Diospyros mespiliformis	644	2,611,000	LC	1404	VU
Elaeis guineensis	2070	1,244,000	LC	752	VU
Khaya senegalensis	200	1,791,000	LC	356	EN
Manilkara obovata	173	1,993,000	LC	552	VU
Mitragyna inermis	513	2,225,000	LC	860	VU
Parinari congensis	54	1,419,000	LC	188	EN
Paullinia pinnata	213	2,183,000	LC	664	VU
Pterocarpus santalinoides	228	1,661,000	LC	688	VU
Saba senegalensis	125	1,312,000	LC	436	EN
Syzygium guineense	168	1,697,000	LC	568	VU
Uapaca togoensis	300	1,469,000	LC	736	VU
Uvaria chamae	192	1,721,000	LC	648	VU
Vitex chrysocarpa	91	1,093,000	LC	220	EN
Vitex doniana	229	2,131,000	LC	636	VU
Xylopia longipetala	23	573,000	LC	64	EN

3.3 Genetic Population Structure of Gallery Forest Species

The results of a 'Principal Coordinates Analysis' (PCoA) revealed a relatively weak genetic population structure in the four study species (see fig. 32). The *STRUCTURE* analyses of the AFLP markers favoured a clustering into three distinct population for all study species (K = 3). The F_{ST} values varied considerably among the four study species (Table 3). F_{ST} is a standard measure of genetic distance between populations and can be between 0 and 1, where 0 means complete sharing of genetic material and 1 means no sharing. For *Anogeissus leiocarpa* the distance between 'population orange' and 'population green' was shortest and the distance between 'population orange' and 'population blue' was largest (table 3). For *Diospyros mespiliformis* the distances between all populations were similar (table 3). For *Paullinia pinnata* the distance between 'population green' and 'population blue' was shortest and the distance between 'population orange' and population green' was largest (table 3). *Pterocarpus santalinoides* showed much higher F_{ST} values than the other three species. The genetic distance between 'population orange' and 'population green' was shortest (but still higher than the highest F_{ST} values for the other three species) and the distance between 'population green' and 'population blue' was largest (table 3). In general, the individuals of these populations showed a relative strong admixture.

The geographic clustering of the populations showed no clear overall pattern. Figures 3333 and 34 visualize the geographic distribution of the three populations resulting from the *STRUCTURE* analysis using a Voronoi tessellation. A Voronoi tessellation is the division of an area into subareas based on specified points (in this case coordinates of individuals). All area that is closer to a specific point than to any other is assigned to that point. That is, the area that is closer to one individual than to any other is coloured in the colour that belongs to the individual's population. In *A. leiocarpa*, the three populations showed a weak geographic pattern (fig. 33A). 'Population orange' formed a relatively homogeneous cluster in the south-west of the country while 'population blue' formed a distinctive cluster in the northwest of the country. 'Population green' formed several clusters throughout the country. Few individuals of all populations were scattered throughout the study area*. D. mespiliformis* was divided into three geographically relative homogenous populations of similar size roughly following perpendicular bands (fig. 33B). In this case 'population orange' was confined to the west of the country, 'population green' occupied the centre and 'population blue' was confined to the east of the country. In *P. pinnata* two of the three populations formed a western (orange) and an eastern and central cluster (blue) (fig. 34A). The third population was scattered between the two others. However, the geographic clustering in this species was weak, and individuals from all populations were spread throughout the study area. The populations of *P. santalinoides* did not show a clear pattern (fig. 34B).

The *STRUCTURE* populations of all study species did not correspond with the watersheds of the major Burkinian river systems (fig. 35). In *A. leiocarpa* all three populations were spread over the river basins and there was admixture across basin borders. The same pattern emerged in *D. mespiliformis*. However, in this species the West Coast river basin was dominated by one population (orange in fig. 35), but individuals of this population were also common in the Niger basin. The closest agreement between genetic structure and river basins occurred in *P. pinnata*: For this species the samples from the Niger basin formed a homogenous population (2 individuals) and also the West Coast basin was almost homogenous (11 individuals). However, the Volta basin was genetically heterogeneous with individuals from all three populations. In *P. santalinoides* the individuals from the West Coast and Volta basin were assigned to multiple populations and showed strong admixture. For this species no samples from the Niger basin were available.

The results of the *STRUCTURE* analyses were supported by the *SplitsTree* networks, which showed only a weak genetic structure and no clear clustering into different populations for all four study species (fig. 36). The networks were star-like for all species, indicating much higher within-cluster-distance than between-cluster-distance. Additionally, there was no pattern between genetic clustering and river basin association. The results for *A. leiocarpa* showed a strongly connected network with individuals from all river basins appearing in all parts of the network (fig. 36A). The network for *D. mespiliformis* showed a weak clustering into four different groups. Again, there was no link between river basins and genetic structure, as individuals from all river basins were spread throughout the network (fig. 36B). There was also only very weak clustering in the *P. pinnata* network, but concordant with the *STRUCTURE* results *P. pinnata* showed the most pronounced (but still weak) correlation between river basins and genetic population structure, with a tendency for the individuals from the West Coast Basin to cluster together (fig. 36C). The network for *P. santalinoides* showed a clustering into two major groups, with one group consisting only of individuals from the West Coast basin. However, the second cluster was mixed with individuals from the West Coast and Volta basin (fig. 36D).

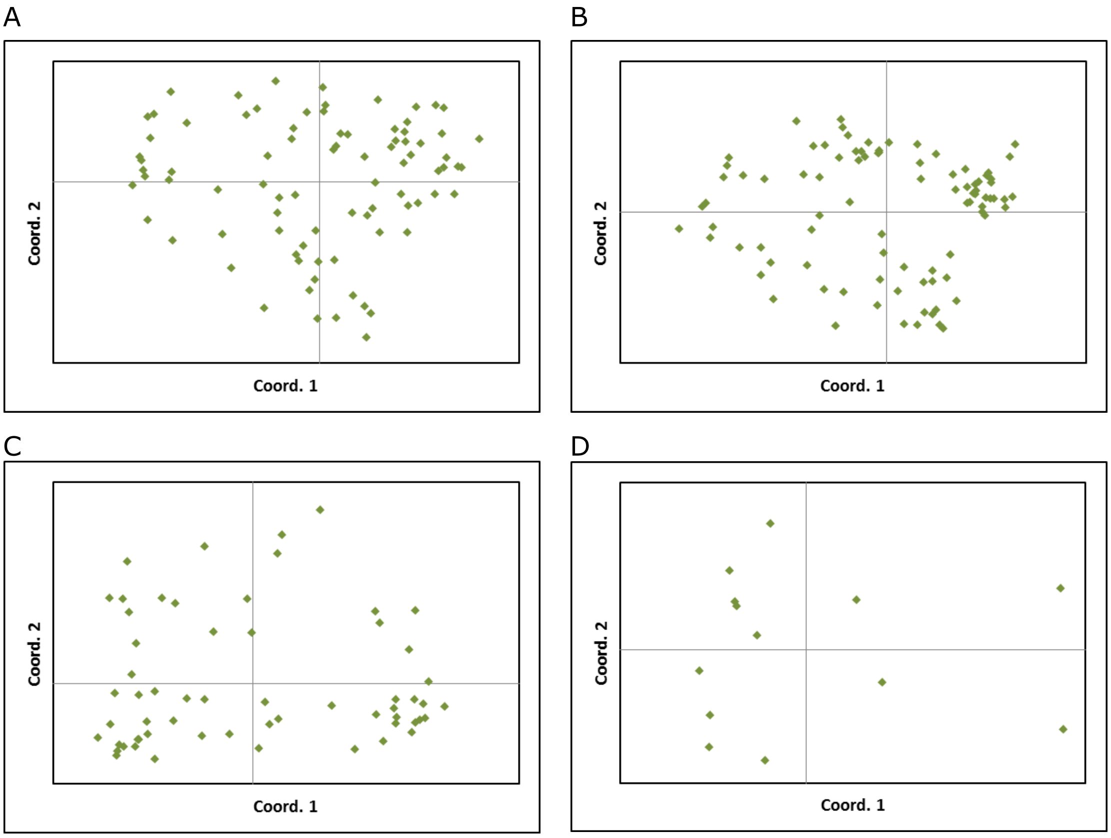

Fig. 32: Principal Coordinates Analysis of the genetic data for the four study species. A) *Anogeissus leiocarpa*; B) *Diospyros mespiliformis*; C) *Paullinia pinnata*; D) *Pterocarpus santalinoides*.

Table 3: Genetic distance between populations, expressed as F_{ST} values. The value for F_{ST} can be between 0 and 1, where 0 means complete sharing of genetic material and 1 means no sharing. Distance between the orange and the green population is smallest for *A. leiocarpa*. Distance between the orange and the blue population is smallest for *D. mespiliformis*. Distance between the green and the blue population ist smallest for *A. leiocarpa*. Distances for all populations are highest for *P. santalinoides*.

Species	Distance between population (F_{ST} value)		
	orange–green	orange–blue	green–blue
Anogeissus leiocarpa	0.1761	0.3543	0.2393
Diospyros mespiliformis	0.3078	0.3001	0.2616
Paullinia pinnata	0.4006	0.3098	0.2878
Pterocarpus santalinoides	0.5778	0.7462	0.8109

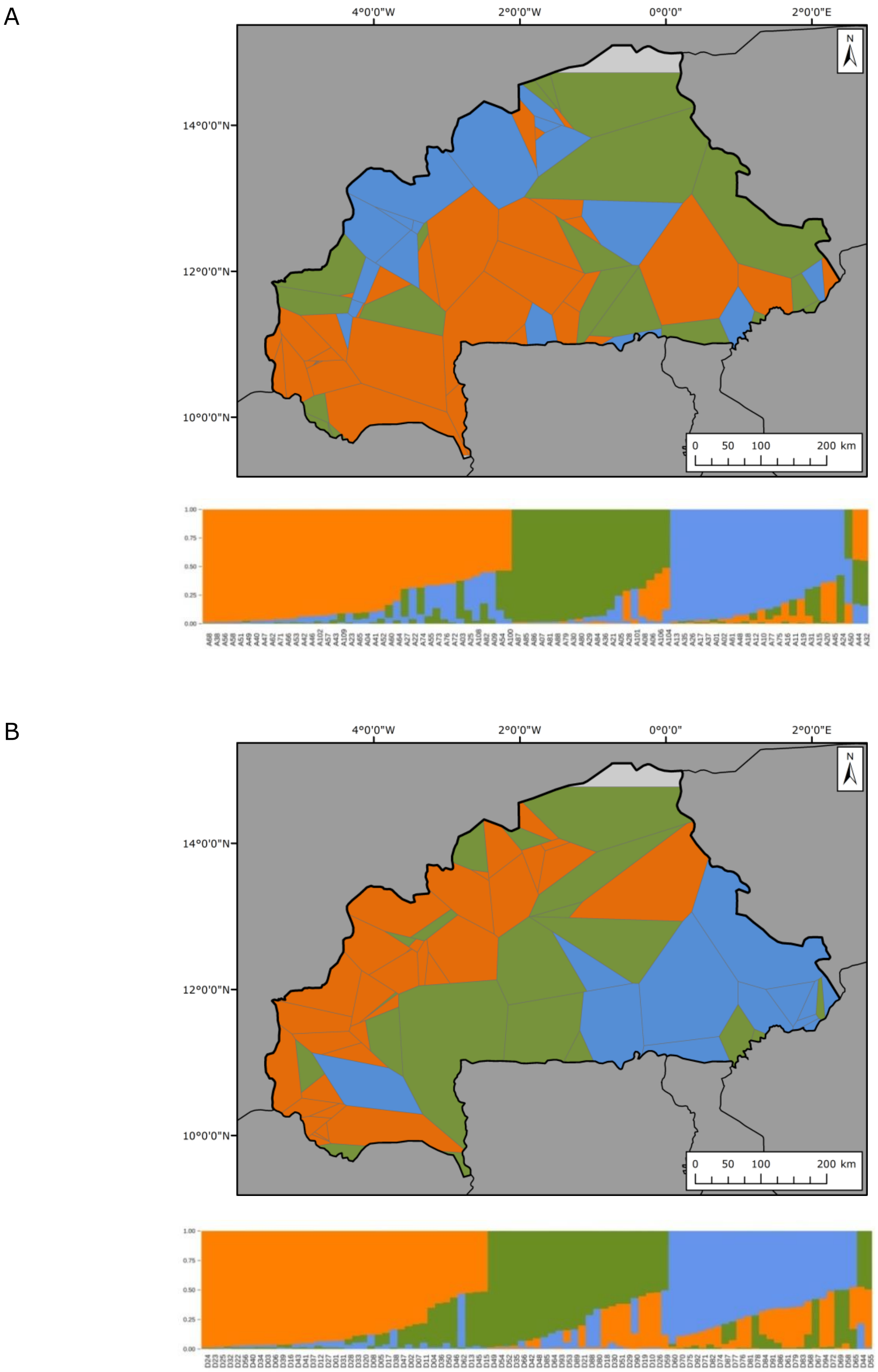

Fig. 33: Genetic population structure using the program *STRUCTURE*. A) *Anogeissus leiocarpa*; B) *Diospyros mespiliformis*. Bar plot generated using the program *Structure Plot*. The colours represent different genetic populations. The Voronoi tessellation gives an impression of the spatial distribution of the three populations.

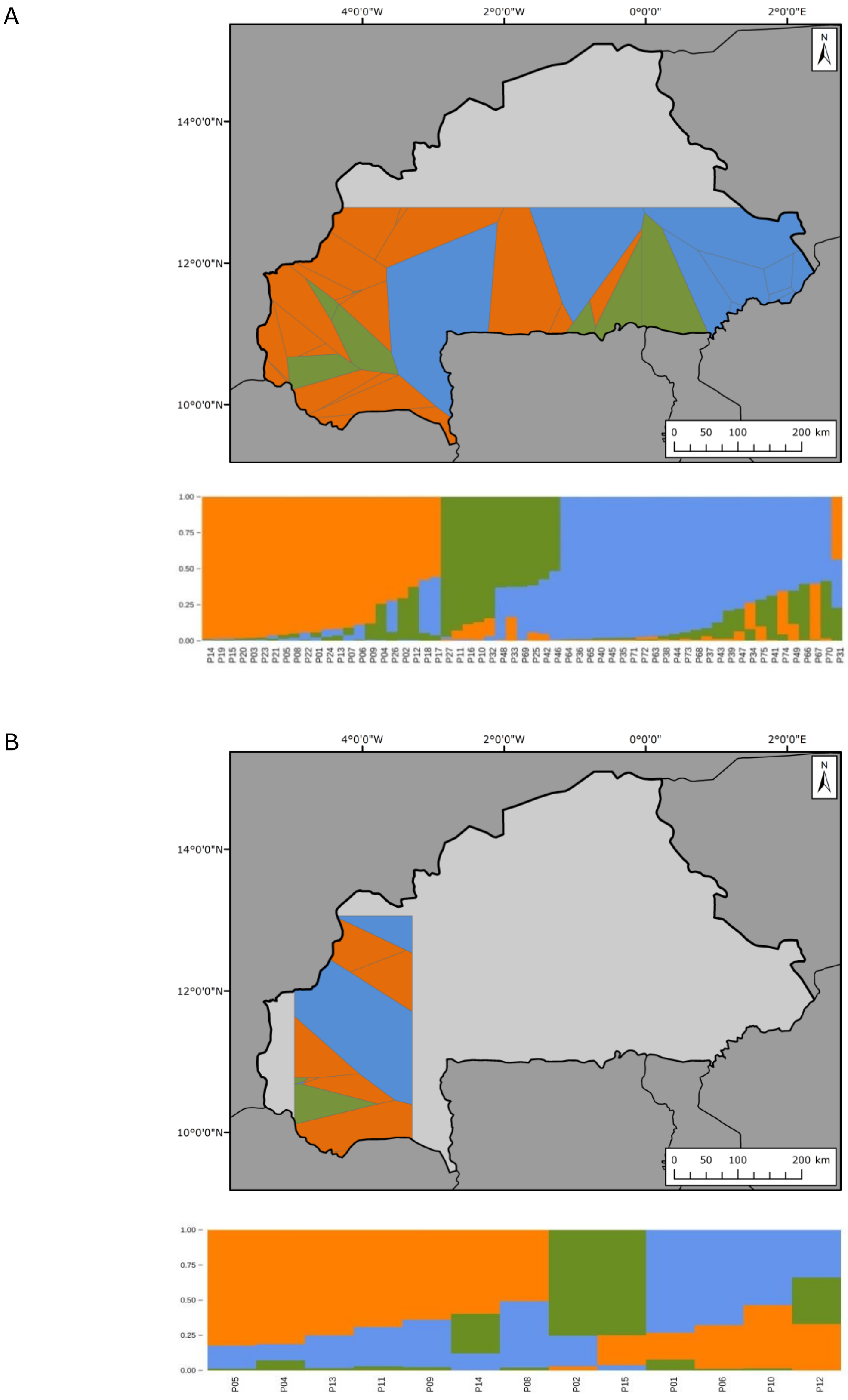

Fig. 34: Genetic population structure using the program *STRUCTURE*. A) *Paullinia pinnata*; B) *Pterocarpus santalinoides.* Bar plot generated using the program *Structure Plot*. The colours represent different genetic populations. The Voronoi tessellation gives an impression of the spatial distribution of the three populations.

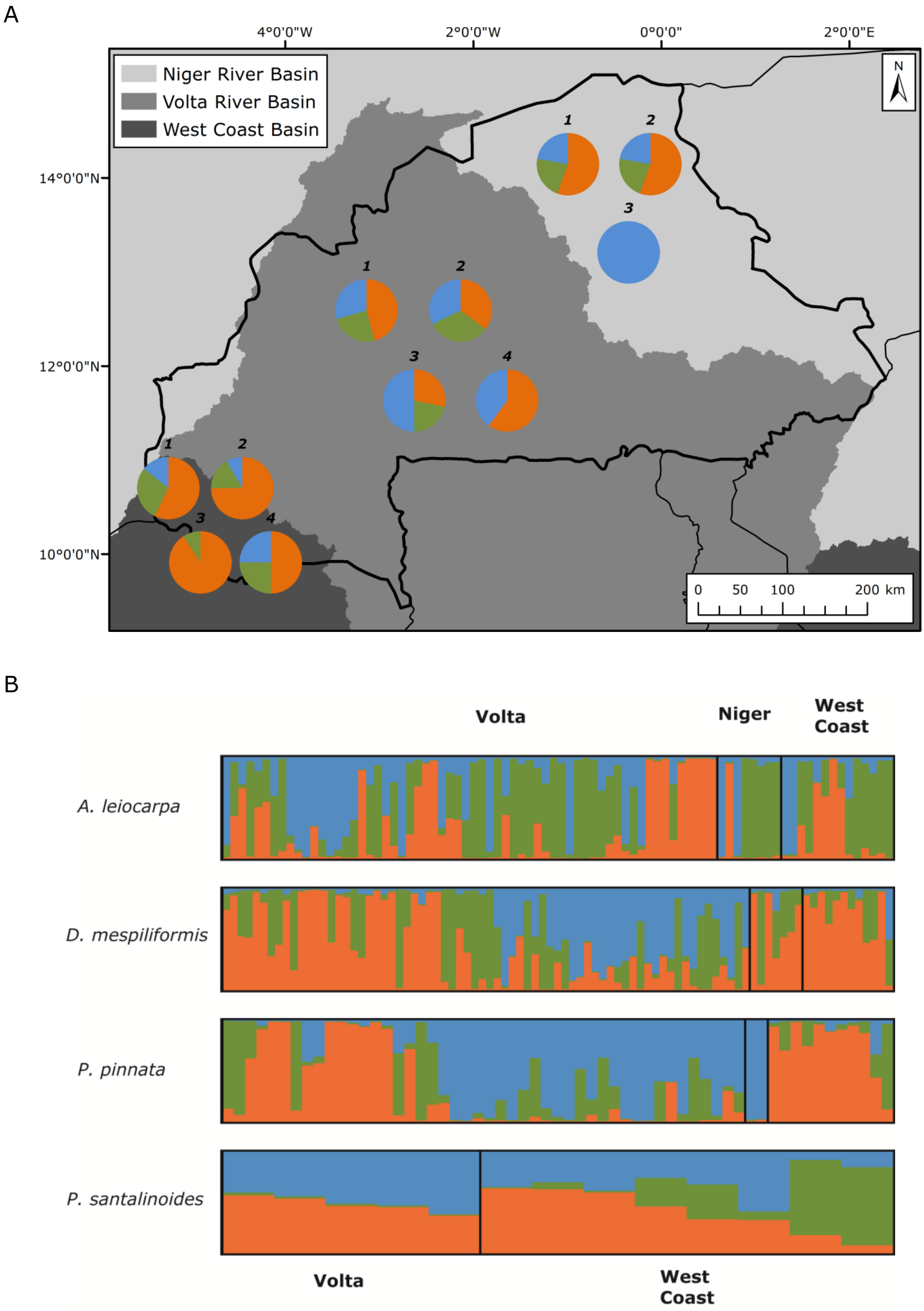

Fig. 35: Genetically identified population structure and river basins in Burkina Faso. A) Pie charts show the proportion of individuals collected in the respective river basin belonging to a population according to *STRUCTURE* results. 1 = *Anogeissus leiocarpa*; 2 = *Diospyros mespiliformis*, 3 = *Paullinina pinnata*; 4 = *Pterocarpus santalinoides*; B) Assignment of individuals to the populations according to *STRUCTURE* collected in the three river basins using the program *DISTRUCT*. Each bar represents an individual, bar colours showing assignment to population. Bars with more than one colour indicate admixture for this individual, colours represent populations.

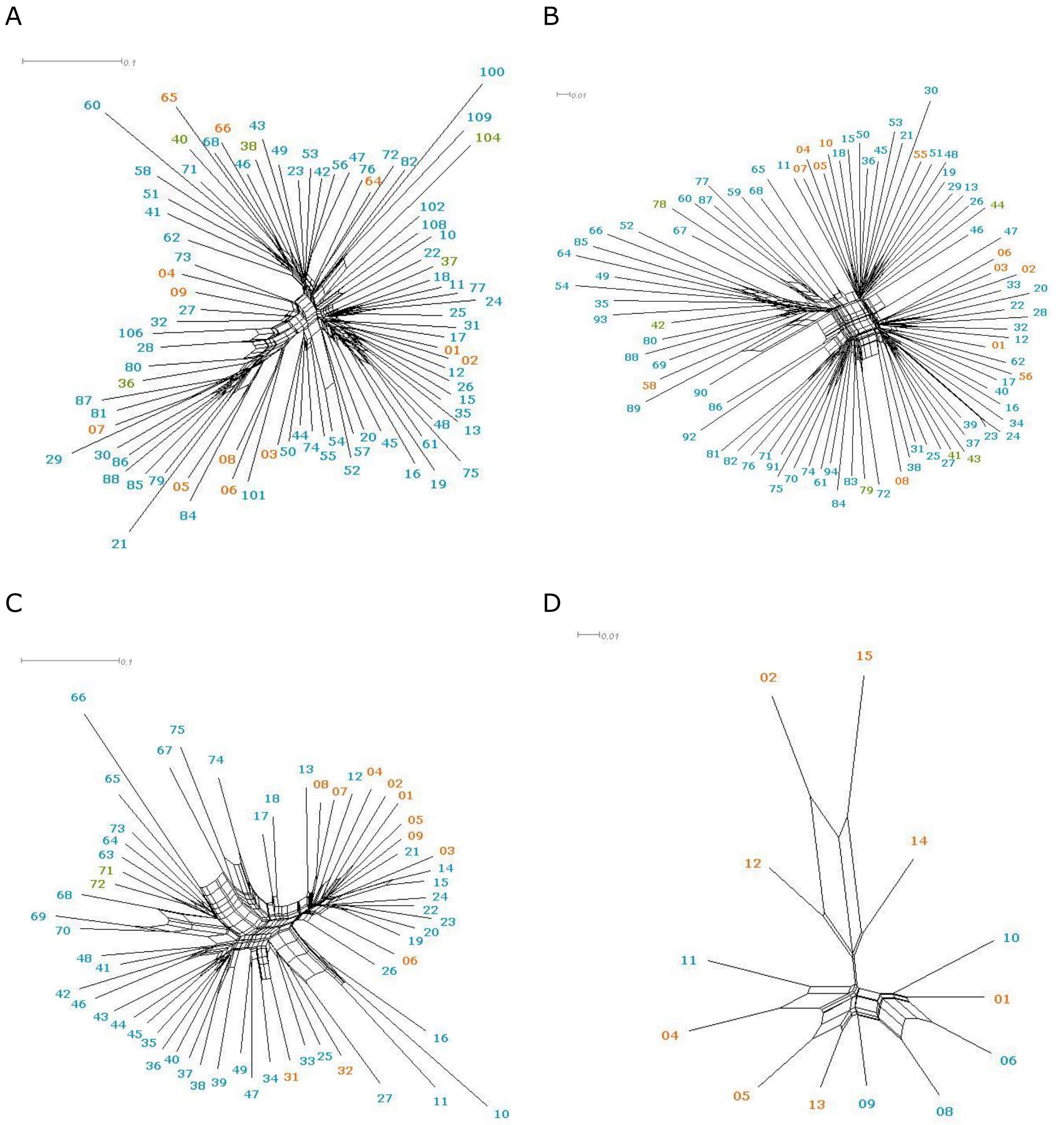

Fig. 36: SplitsTree networks showing the relationship between the individuals of the four study species. The numbers in the network show the sample ID and the colours show the different river basins. Green: Niger River Basin, blue: Volta River Basin, orange: West Coast Basin. A) *Anogeissus leiocarpa*; B) *Diospyros mespiliformis;* C) *Paullinia pinnata;* D) *Pterocarpus santalinoides*.

A third analysis approach using *BAPS* and Bayesian population delimitation supported the results found with *STRUCTURE* and *SplitsTree*. The analysis found an optimal number of three populations for *Anogeissus leiocarpa* (probability: 1.00), *Diospyros mespiliformis* (probability: 1.00) and *Paullinia pinnata* (probability: 0.99) and an optimal partition of two populations for *Pterocarpus santalinoides* (probability: 0.99). The results support a correlation between geography and genetic structure, but this structure was not clear and the distributions of the different genetic populations were mostly overlapping. In general, the geographic patterns were not consistent among the four study species and did not correlate with the major river basins. For *A. leiocarpa* 'population orange' (fig. 37A) comprised 42 sampled individuals (50 %). The two remaining populations comprised 20 and 22 individuals (24 % and 26 %), respectively. 'Population orange' was geographically clustered in the south and central parts of the study area, whereas 'population blue' and 'green' were clustered in the northeast and northwest of the country respectively (fig. 37A). However, few individuals from all populations were scattered across the country. There was no correlation between river basins and the genetic populations in *A. leiocarpa*. In *D. mespiliformis* the three population had different sizes ('population orange': 45 (51 %); 'population green': 28 (31 %); 'population blue': 16 (18 %). The three populations formed geographically relatively homogenous groups (fig. 37B). 'Population orange' was mainly confined to the western and northern parts of the study area. 'Population green' was geographically divided between a homogenous eastern group and a smaller group in the central west of the country. 'Population blue' consisted of a homogenous cluster in central Burkina Faso and some individuals scattered throughout the country. There was no correlation between the river basins and the genetic structure in *D. mespiliformis. P. pinnata* was divided into three differently sized populations (fig. 37C). The biggest population comprised 25 individuals (59 %, 'population blue'), the second population comprised 20 individuals (34 %, 'population orange') and the third population was by far the smallest with only 4 individuals (7 %, 'population green'). A part of 'population blue' formed a homogenous cluster in the east of the study area, but other individuals of this population were scattered throughout the country. The other two populations were mostly spread over the country, although 'population orange' more to the west of the country. There was no correlation between river basins and genetic populations in *P. pinnata*. The individuals of *Pterocarpus santalinoides* were divided into two populations, with one representing the majority of the samples (11 and 2 samples respectively). The populations formed homogeneous groups (fig. 37D). Due to the small geographic sampling extent the results of *P. santalinoides* only hold limited information concerning the correlation between river basins and genetic structure.

All analyses of the AFLP markers generally agreed in the most likely number of genetic populations (3) in the study area, and this number was generally consistent between study species. The degree of geographic clustering differed between analysis method and study species. In general, geographic clustering was rather weak and no clear cross-taxonomic pattern emerged. None of the analyses or species showed support for a correlation between river basins and genetic population structure.

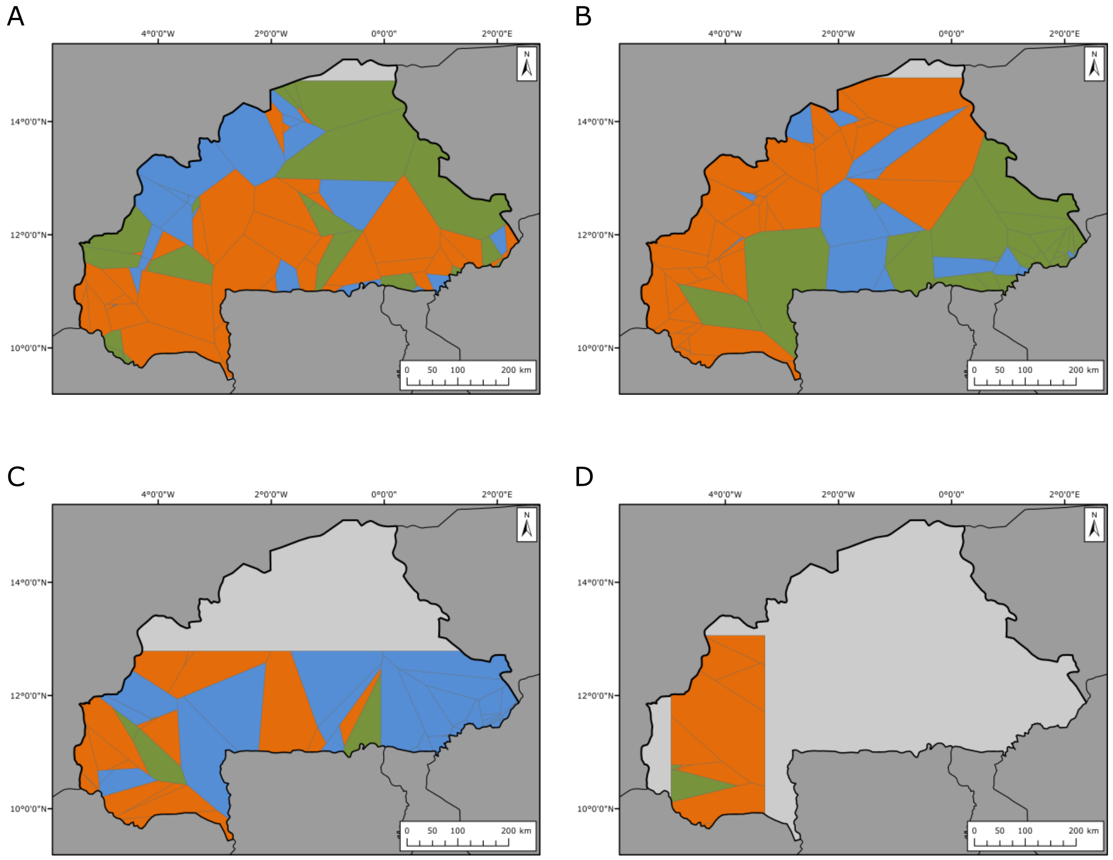

Fig. 37: Voronoi tessellation of the individuals of A) *Anogeissus leiocarpa*; B) *Diospyros mespiliformis;* C) *Paullinia pinnata*; D) *Pterocarpus santalinoides*, using the program *BAPS* (Bayesian Analysis of Population Structure). The colours represent different genetic populations red: population 1, green: population 2, blue: population 3. The Voronoi tessellation gives an impression of the spatial distribution of the three populations.

3.4 Genetic Population Structure through Time

The species-tree diffusion models revealed general dispersal patterns of how gallery forest (GF) species colonized the study area. For all four study species the models inferred a recolonization from the south, with an early split into a western and an eastern population. This east-west disjunction was mostly followed by north-south dispersal in both populations. As time proceeded dispersal became more random and occurred throughout the country. This led to the original disjunct patterns being overwritten and lost in all species. Figures 38-41 show snapshots of the results of the species-tree diffusion models at four time slices for *Anogeissus leiocarpa*, *Diospyros mespiliformis*, *Paullinia pinnata* and *Pterocarpus santalinoides*. The entire time series are available at the Zenodo repository (doi:10.5281/zenodo.376190). The geographic location of each node in a phylogenetic tree was inferred using the location of the tips of the tree. The blue polygons in the figures represent the inferred area with uncertainty; the black lines connect the inferred geographic location of the nodes in the tree. The first genetic split in *A. leiocarpa* was inferred as an east-west split in central southern Burkina Faso (BFA) (fig. 38A), leading to two relative separated populations, one in central and west BFA ("central") and one in eastern BFA ("eastern", fig. 38B). A number of local splits followed in both populations, with the central population dispersing westwards and the eastern population dispersing predominantly southwards into what today is northern Benin (fig. 38C). The youngest splits indicated a rapid and relatively unlimited dispersal throughout entire BFA with no clear patterns recognizable (fig. 38D). In *D. mespiliformis* a similar pattern was observed. The first split was inferred close to the centre of the study area (fig. 39A). In this species a pronounced split into an eastern and a western population was inferred (fig. 39B). While both populations showed a number of separate local splits and dispersals, the general direction of dispersal was different. The western group dispersed predominantly north- and southwards, and barely towards the east, while the eastern population mainly dispersed westwards (fig. 39C). Dispersal distance was generally lower in the eastern group. In the last time slice dispersal distances increase and dispersal becomes more random, but the general disjunction into an eastern and western population mostly remains (fig. 39D). *P. pinnata* showed an early split into three groups: a western, central and eastern population (fig. 40A+B). Subsequently, all three groups dispersed locally. The western group disperses further westwards. The eastern group disperses mostly north- and southwards; in this case some events covered considerable distances and reached until what today is southern Benin. The central group showed only few splits, but also dispersed southwards (fig. 40C). Similar to *A. leiocarpa* and *D. mespiliformis*, dispersal became more random, with a dispersal of the western group to the east and the eastern group to the west, as time proceeded, but the general pattern remains (fig. 40D). *P. santalinoides* showed a clear split into a northwestern and a southeastern population (fig. 41A+B). Interestingly, two separate, independent splits into west and east occurred a second time from the same origin (fig. 41C+D).

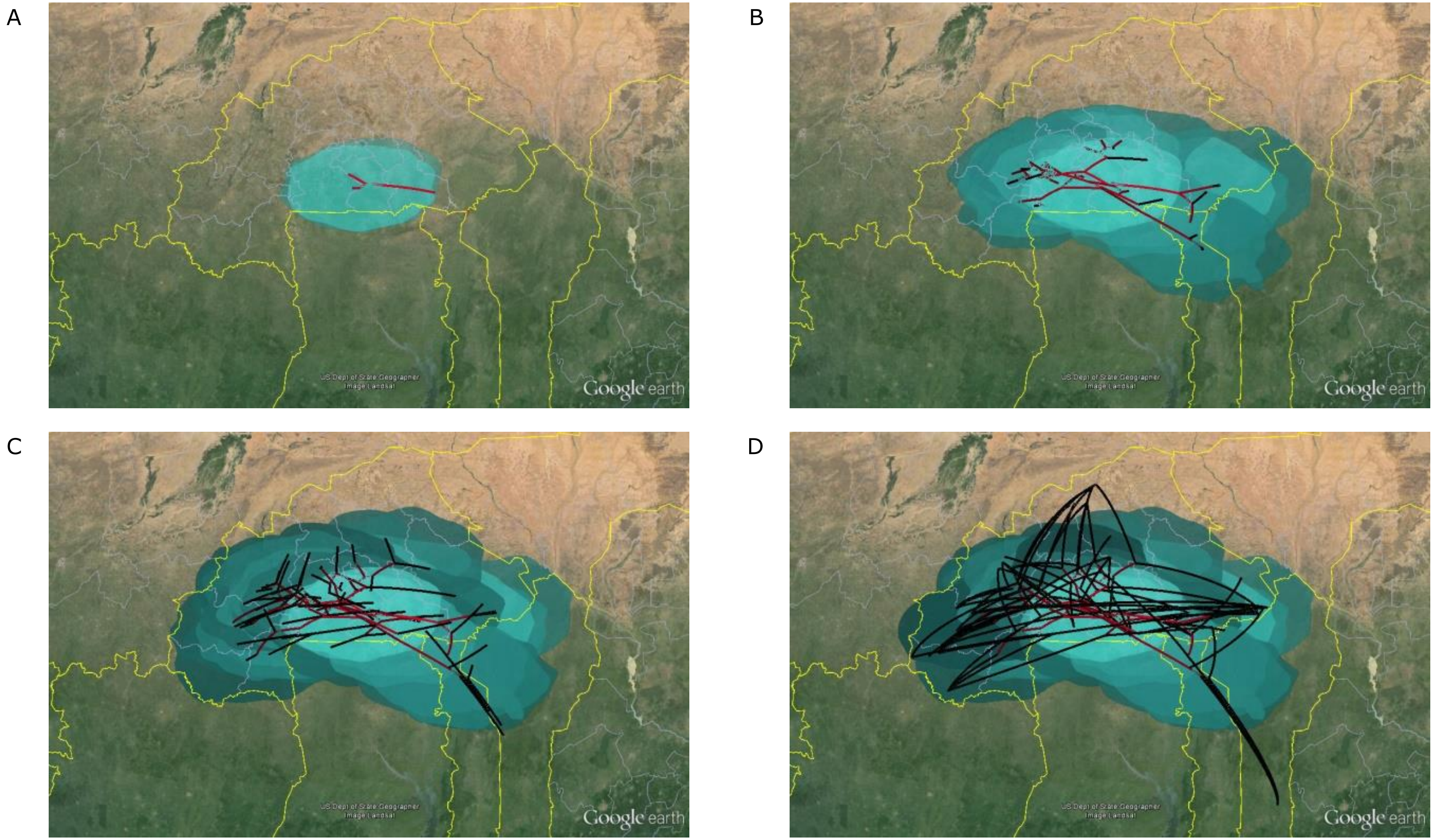

Fig. 38: Dispersal of *Anogeissus leiocarpa* through time. Time slices are relative time as no absolute dating of AFLP data was possible. The nodes of the black lines represent nodes in a phylogenetic tree inferred from the AFLP data. The blue polygons represent the inferred location of the split including uncertainty.

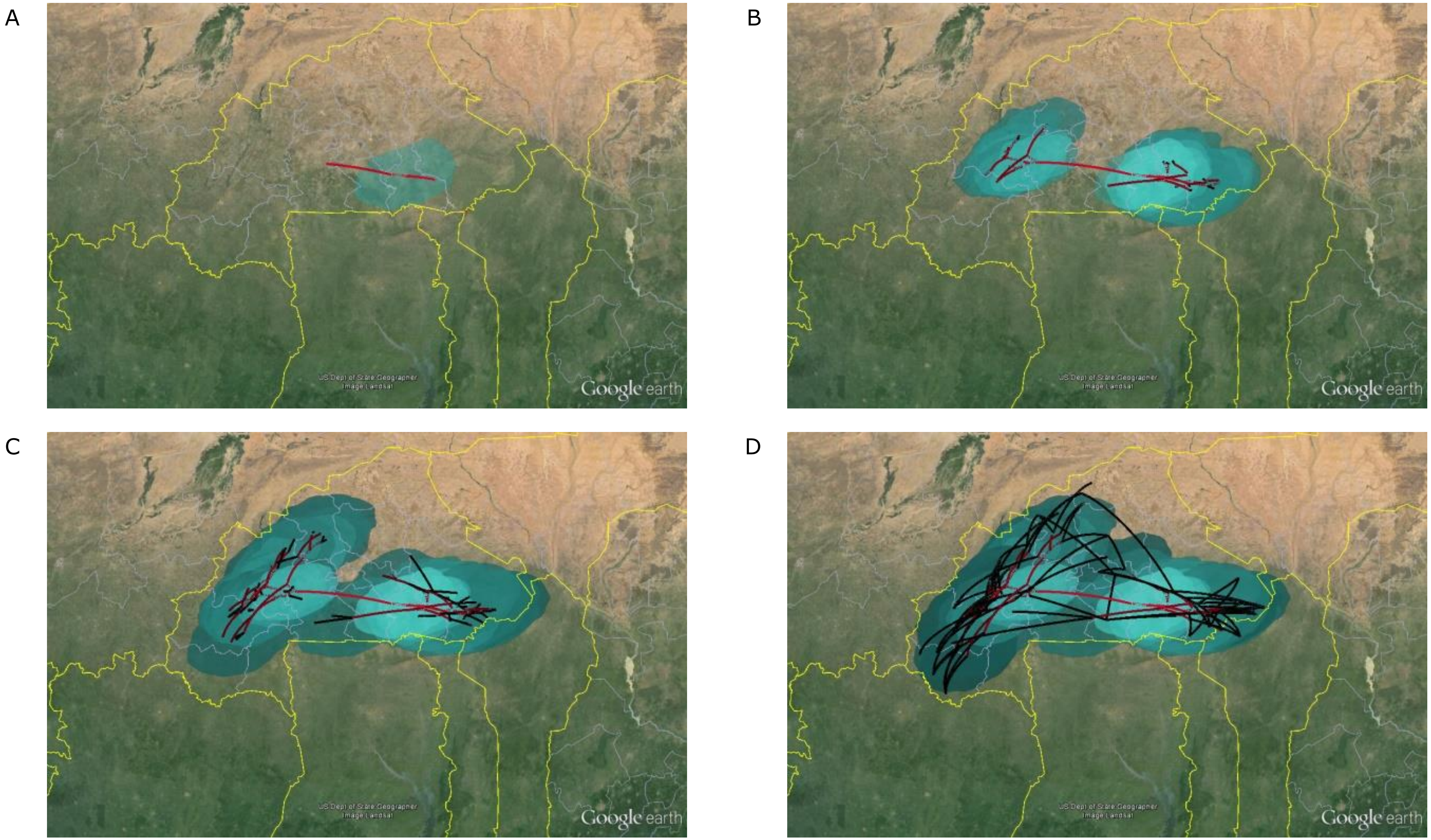

Fig. 39: Dispersal of *Diospyros mespiliformis* through time. Time slices are relative time as no absolute dating of AFLP data was possible. The nodes of the black lines represent nodes in a phylogenetic tree inferred from the AFLP data. The blue polygons represent the inferred location of the split including uncertainty.

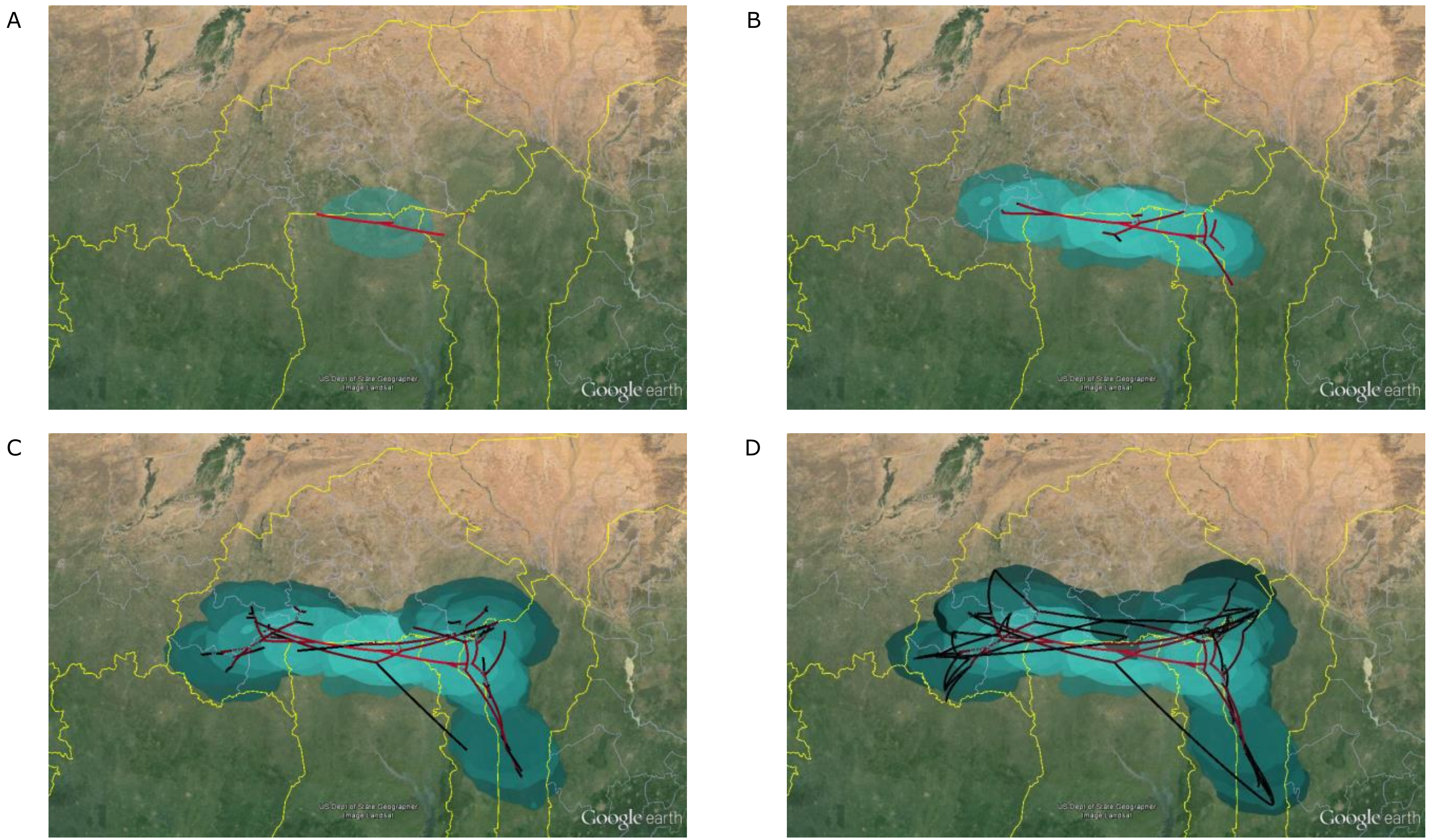

Fig. 40: Dispersal of *Paullinia pinnata* through time. Time slices are relative time as no absolute dating of AFLP data was possible. The nodes of the black lines represent nodes in a phylogenetic tree inferred from the AFLP data. The blue polygons represent the inferred location of the split including uncertainty.

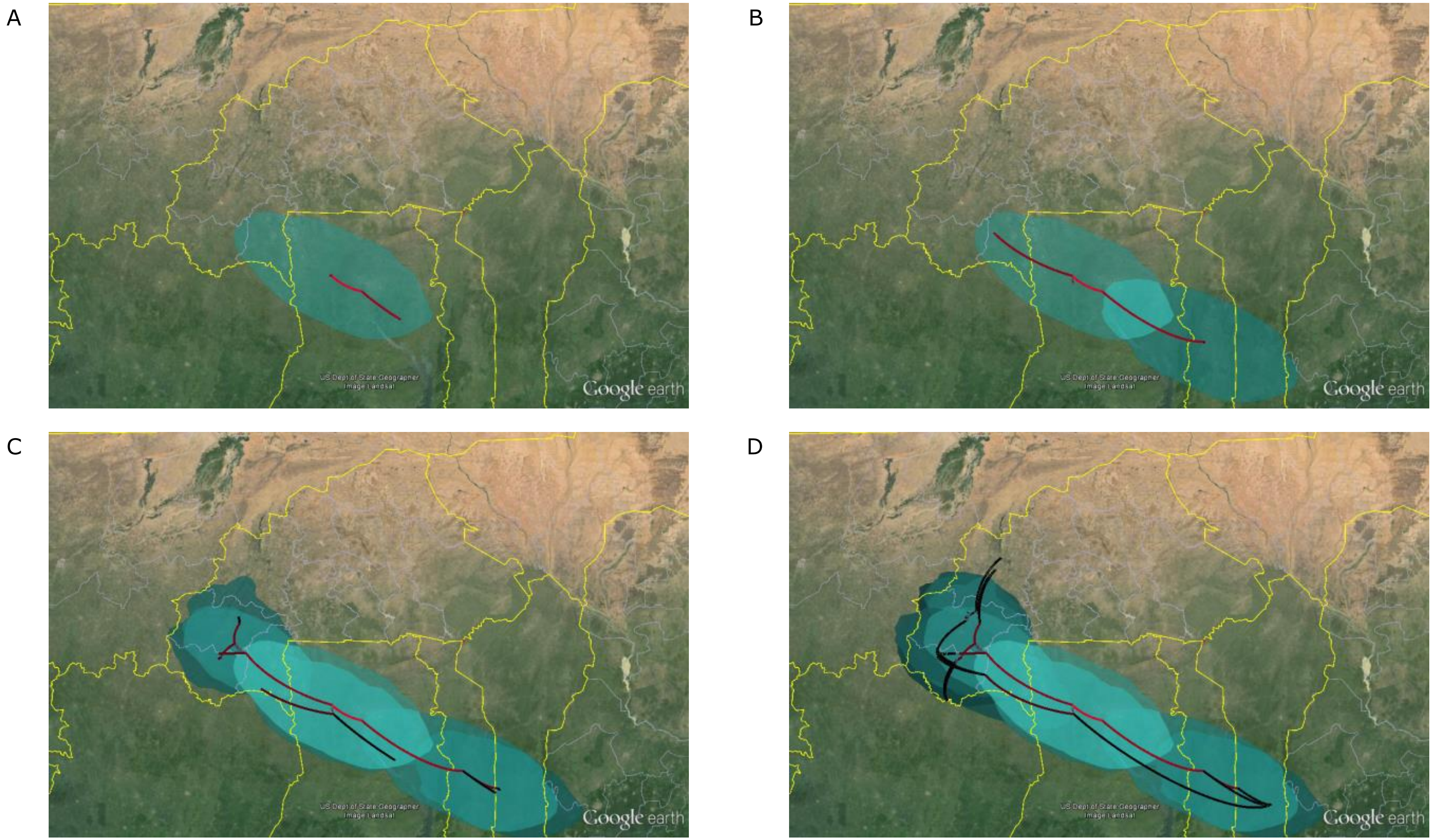

Fig. 41: Dispersal of *Pterocarpus santalinoides* through time. Time slices are relative time as no absolute dating of AFLP data was possible. The nodes of the black lines represent nodes in a phylogenetic tree inferred from the AFLP data. The blue polygons represent the inferred location of the split including uncertainty.

3.5 Genetic Population Structure and Environment

Correlation between genetic structure and geographic distance as well as between genetic structure and environmental variables were tested for the four study species. A Mantel test found little correlation between geographic distance and genetic distance of a sample in three out of four study species: *Anogeissus leiocarpa* (R_{xy} = 0.087), *Diospyros mespiliformis* (R_{xy} = 0.274) and *Pterocarpus santalinoides* (R_{xy} = -0.035). A slight positive correlation was found for *Paullinia pinnata* (R_{xy} = 0.5, R^2 = 0.25). R_{xy} can be between -1 and 1, for values closed to zero there is no correlation, for values close to -1 there is a strong negative correlation, for values close to +1 there is a strong positive correlation. Figure 42 shows the correlation between geographic and genetic distance matrix.

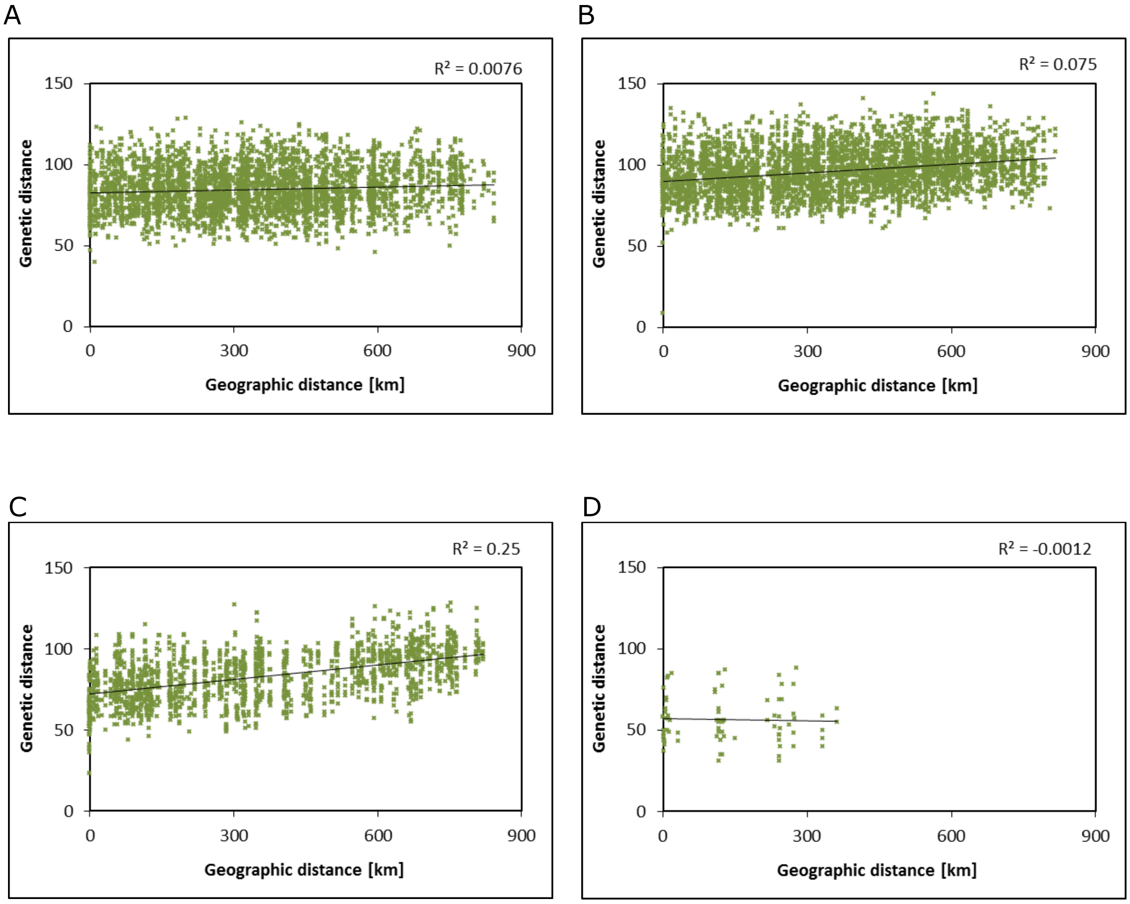

Fig. 42: Correlation of geographic and genetic distance of A) *Anogeissus leiocarpa*; B) *Diospyros mespiliformis*; C) *Paullinia pinnata;* D) *Pterocarpus santalinoides*. Correlation is strongest for *P. pinnata*.

There was a significant correlation between environmental factors and the genetic clusters. We found 35 significant correlations based on the *STRUCTURE* classification and 25 significant correlations based on the *BAPS* classification (table 4 and table 5). The most often recovered correlations over all study species were 'mean annual temperature', 'maximum temperature of the warmest month' and 'annual precipitation'. The general correlation of genetic clusters with environmental variables as well as the importance of different factors varied among the four study species. In *Anogeissus leiocarpa* the *STRUCTURE* and *BAPS* clusters were significantly correlated with the same nine environmental variables, including eight climate variables as well as 'top soil bulk density' (table 4). Correlation was most significant with 'mean temperature of the wettest quarter', followed by 'mean annual temperature'. In *D. mespiliformis* the *STRUCTURE* clusters correlated with seven climatic variables as well as 'top soil organic carbon content' and the *BAPS* clusters correlated with seven climatic variables. Correlation was highest for the 'mean temperature of the driest quarter' and 'mean temperature of the coldest quarter' followed by the 'precipitation in the driest quarter' and 'precipitation of the driest month' in the case of the *STRUCTURE* clusters and for the 'mean temperature of the driest quarter' followed by 'precipitation of the driest month' and 'precipitation of the driest quarter' in the case of the *BAPS* clusters. In *P. pinnata* differences among *STRUCTURE* clusters were significant for 17 climatic variables and 'top soil sand fraction' and for 11 climate variables for the *BAPS* clusters (table 5). The differences were highly significant in most cases for the *STRUCTURE* clusters and most significant for the 'precipitation of the driest month' and 'precipitation of the driest quarter' for the *BAPS* clusters. No significant differences could be found among the genetic clusters of *P. santalinoides*.

Table 4: Correlation between environmental factors and genetic clusters found by STRUCTURE and BAPS for *Anogeissus leiocarpa* and *Diospyros mespiliformis*. *: $p \leq 0.05$; **: $p \leq 0.01$; *** $p \leq 0.001$

	Anogeissus leiocarpa				*Diospyros mespiliformis*			
Environmental layer	Structure		BAPS		Structure		BAPS	
Top soil pH	$F_{1,82} = 0.355$	$p \geq 0.05$	$F_{1,82} = 0.057$	$p \geq 0.05$	$F_{1,87} = 2.094$	$p \geq 0.05$	$F_{1,87} = 2.604$	$p \geq 0.05$
Top soil sand fraction	$F_{1,82} = 0.216$	$p \geq 0.05$	$F_{1,82} = 0.554$	$p \geq 0.05$	$F_{1,87} = 3.361$	$p \geq 0.05$	$F_{1,87} = 2.662$	$p \geq 0.05$
Top soil Cation exchange capacity	$F_{1,82} = 0.008$	$p \geq 0.05$	$F_{1,82} = 0.324$	$p \geq 0.05$	$F_{1,87} = 0.003$	$p \geq 0.05$	$F_{1,87} = 0.001$	$p \geq 0.05$
Top soil organic carbon content	$F_{1,82} = 0.885$	$p \geq 0.05$	$F_{1,82} = 1.285$	$p \geq 0.05$	$F_{1,87} = 4.867$	**$p \leq 0.05$ ***	$F_{1,87} = 0.037$	$p \geq 0.05$
Top soil Bulk density	$F_{1,82} = 5.218$	**$p \leq 0.05$ ***	$F_{1,82} = 4.644$	**$p \leq 0.05$ ***	$F_{1,87} = 3.836$	$p \geq 0.05$	$F_{1,87} = 0.198$	$p \geq 0.05$
Mean annual temperature	$F_{1,82} = 6.032$	**$p \leq 0.05$ ***	$F_{1,82} = 5.796$	**$p \leq 0.05$ ***	$F_{1,87} = 3.944$	$p \geq 0.05$	$F_{1,87} = 4.273$	**$p \leq 0.05$ ***
Mean diurnal range	$F_{1,82} = 1.383$	$p \geq 0.05$	$F_{1,82} = 1.808$	$p \geq 0.05$	$F_{1,87} = 0.232$	$p \geq 0.05$	$F_{1,87} = 0.495$	$p \geq 0.05$
Isothermality	$F_{1,82} = 1.067$	$p \geq 0.05$	$F_{1,82} = 1.26$	$p \geq 0.05$	$F_{1,87} = 1.224$	$p \geq 0.05$	$F_{1,87} = 0.004$	$p \geq 0.05$
Temperature seasonality	$F_{1,82} = 4.013$	**$p \leq 0.05$ ***	$F_{1,82} = 4.296$	**$p \leq 0.05$ ***	$F_{1,87} = 0.704$	$p \geq 0.05$	$F_{1,87} = 0.001$	$p \geq 0.05$
Max temperature warmest month	$F_{1,82} = 4.509$	**$p \leq 0.05$ ***	$F_{1,82} = 4.481$	**$p \leq 0.05$ ***	$F_{1,87} = 4.015$	**$p \leq 0.05$ ***	$F_{1,87} = 4.835$	$p \geq 0.05$
Min temperature coldest month	$F_{1,82} = 0.081$	$p \geq 0.05$	$F_{1,82} = 0.007$	$p \geq 0.05$	$F_{1,87} = 8.415$	**$p \leq 0.01$ ****	$F_{1,87} = 4.213$	$p \geq 0.05$
Temperature annual range	$F_{1,82} = 1.734$	$p \geq 0.05$	$F_{1,82} = 2.158$	$p \geq 0.05$	$F_{1,87} = 0.336$	$p \geq 0.05$	$F_{1,87} = 0.007$	$p \geq 0.05$
Mean temperatur of wettest quater	$F_{1,82} = 6.84$	**$p \leq 0.05$ ***	$F_{1,82} = 7.391$	**$p \leq 0.01$ ****	$F_{1,87} = 0.829$	$p \geq 0.05$	$F_{1,87} = 0.049$	$p \geq 0.05$
Mean temperature of driest quater	$F_{1,82} = 0.025$	$p \geq 0.05$	$F_{1,82} = 0.126$	$p \geq 0.05$	$F_{1,87} = 21.1$	**$p \leq 0.001$ *****	$F_{1,87} = 10.49$	**$p \leq 0.01$ ****
Mean temperature of warmest quater	$F_{1,82} = 5.247$	**$p \leq 0.05$ ***	$F_{1,82} = 5.27$	**$p \leq 0.05$ ***	$F_{1,87} = 2.466$	$p \geq 0.05$	$F_{1,87} = 3.108$	$p \geq 0.05$
Mean temperature of coldest quater	$F_{1,82} = 0.314$	$p \geq 0.05$	$F_{1,82} = 0.295$	$p \geq 0.05$	$F_{1,87} = 15.08$	**$p \leq 0.001$ *****	$F_{1,87} = 5.54$	**$p \leq 0.05$ ***
Annual precipitation	$F_{1,82} = 4.718$	**$p \leq 0.05$ ***	$F_{1,82} = 4.774$	**$p \leq 0.05$ ***	$F_{1,87} = 0.565$	$p \geq 0.05$	$F_{1,87} = 0.182$	$p \geq 0.05$
Precipitation of wettest month	$F_{1,82} = 5.407$	**$p \leq 0.05$ ***	$F_{1,82} = 5.423$	**$p \leq 0.05$ ***	$F_{1,87} = 0.751$	$p \geq 0.05$	$F_{1,87} = 0.028$	$p \geq 0.05$
Precipitation of driest month	$F_{1,82} = 1.338$	$p \geq 0.05$	$F_{1,82} = 1.491$	$p \geq 0.05$	$F_{1,87} = 7.853$	**$p \leq 0.01$ ****	$F_{1,87} = 8.964$	**$p \leq 0.01$ ****
Precipitation seasonality	$F_{1,82} = 3.294$	$p \geq 0.05$	$F_{1,82} = 3.614$	$p \geq 0.05$	$F_{1,87} = 0.122$	$p \geq 0.05$	$F_{1,87} = 0.429$	$p \geq 0.05$
Precipitation of wettest quater	$F_{1,82} = 5.171$	**$p \leq 0.05$ ***	$F_{1,82} = 5.123$	**$p \leq 0.05$ ***	$F_{1,87} = 2.278$	$p \geq 0.05$	$F_{1,87} = 0.045$	$p \geq 0.05$
Precipitation of driest quater	$F_{1,82} = 1.618$	$p \geq 0.05$	$F_{1,82} = 1.816$	$p \geq 0.05$	$F_{1,87} = 7.032$	**$p \leq 0.01$ ****	$F_{1,87} = 7.497$	**$p \leq 0.01$ ****
Precipitation of warmest quater	$F_{1,82} = 3.517$	$p \geq 0.05$	$F_{1,82} = 3.656$	$p \geq 0.05$	$F_{1,87} = 0.426$	$p \geq 0.05$	$F_{1,87} = 1.822$	$p \geq 0.05$
Precipitation of coldest quater	$F_{1,82} = 2.632$	$p \geq 0.05$	$F_{1,82} = 3.193$	$p \geq 0.05$	$F_{1,87} = 4.268$	**$p \leq 0.05$ ***	$F_{1,87} = 3.122$	$p \geq 0.05$

Table 5: Correlation between environmental factors and genetic clusters found by STRUCTURE and BAPS for *Paullinia pinnata* and *Pterocarpus santalinoides.* *: $p \leq 0.05$; **: $p \leq 0.01$; *** $p \leq 0.001$

Environmental layer	*Paulllinia pinnata*				*Pterocarpus santalinoides*			
	Structure		BAPS		Structure		BAPS	
Top soil pH	$F_{1, 57} = 0.836$	$p \geq 0.05$	$F_{1, 57} = 1.187$	$p \geq 0.05$	$F_{1, 11} = 0.499$	$p \geq 0.05$	$F_{1, 11} = 0.003$	$p \geq 0.05$
Top soil sand fraction	$F_{1, 57} = 12.63$	**$p \leq 0.001$ *****	$F_{1, 57} = 1.584$	$p \geq 0.05$	$F_{1, 11} = 0.003$	$p \geq 0.05$	$F_{1, 11} = 0.955$	$p \geq 0.05$
Top soil Cation exchange capacity	$F_{1, 57} = 1.903$	$p \geq 0.05$	$F_{1, 57} = 0.046$	$p \geq 0.05$	$F_{1, 11} = 0.478$	$p \geq 0.05$	$F_{1, 11} = 0.394$	$p \geq 0.05$
Top soil organic carbon content	$F_{1, 57} = 1.839$	$p \geq 0.05$	$F_{1, 57} = 0.074$	$p \geq 0.05$	$F_{1, 11} = 0.173$	$p \geq 0.05$	$F_{1, 11} = 1.47$	$p \geq 0.05$
Top soil Bulk density	$F_{1, 57} = 0.544$	$p \geq 0.05$	$F_{1, 57} = 0.521$	$p \geq 0.05$	$F_{1, 11} = 0.153$	$p \geq 0.05$	$F_{1, 11} = 0.03$	$p \geq 0.05$
Mean annual temperature	$F_{1, 57} = 36.76$	**$p \leq 0.001$ *****	$F_{1, 57} = 4.423$	**$p \leq 0.05$ ***	$F_{1, 11} = 0.229$	$p \geq 0.05$	$F_{1, 11} = 0.079$	$p \geq 0.05$
Mean diurnal range	$F_{1, 57} = 9.009$	**$p \leq 0.01$ ****	$F_{1, 57} = 9.427$	**$p \leq 0.01$ ****	$F_{1, 11} = 2.464$	$p \geq 0.05$	$F_{1, 11} = 0.11$	$p \geq 0.05$
Isothermality	$F_{1, 57} = 0.561$	$p \geq 0.05$	$F_{1, 57} = 0.923$	$p \geq 0.05$	$F_{1, 11} = 1.727$	$p \geq 0.05$	$F_{1, 11} = 0.144$	$p \geq 0.05$
Temperature seasonality	$F_{1, 57} = 12.97$	**$p \leq 0.001$ *****	$F_{1, 57} = 5.775$	**$p \leq 0.05$ ***	$F_{1, 11} = 0.677$	$p \geq 0.05$	$F_{1, 11} = 0.327$	$p \geq 0.05$
Max temperature warmest month	$F_{1, 57} = 42.81$	**$p \leq 0.001$ *****	$F_{1, 57} = 9.046$	**$p \leq 0.01$ ****	$F_{1, 11} = 0.387$	$p \geq 0.05$	$F_{1, 11} = 0.218$	$p \geq 0.05$
Min temperature coldest month	$F_{1, 57} = 4.828$	**$p \leq 0.05$ ***	$F_{1, 57} = 0$	$p \geq 0.05$	$F_{1, 11} = 1.911$	$p \geq 0.05$	$F_{1, 11} = 0.039$	$p \geq 0.05$
Temperature annual range	$F_{1, 57} = 4.673$	**$p \leq 0.05$ ***	$F_{1, 57} = 5.396$	**$p \leq 0.05$ ***	$F_{1, 11} = 2.234$	$p \geq 0.05$	$F_{1, 11} = 0.093$	$p \geq 0.05$
Mean temperatur of wettest quater	$F_{1, 57} = 19.61$	**$p \leq 0.001$ *****	$F_{1, 57} = 3.189$	$p \geq 0.05$	$F_{1, 11} = 1.289$	$p \geq 0.05$	$F_{1, 11} = 0.006$	$p \geq 0.05$
Mean temperature of driest quater	$F_{1, 57} = 13.89$	**$p \leq 0.001$ *****	$F_{1, 57} = 1.453$	$p \geq 0.05$	$F_{1, 11} = 0.897$	$p \geq 0.05$	$F_{1, 11} = 0.056$	$p \geq 0.05$
Mean temperature of warmest quater	$F_{1, 57} = 38.79$	**$p \leq 0.001$ *****	$F_{1, 57} = 7.288$	**$p \leq 0.01$ ****	$F_{1, 11} = 0.419$	$p \geq 0.05$	$F_{1, 11} = 0.115$	$p \geq 0.05$
Mean temperature of coldest quater	$F_{1, 57} = 27.03$	**$p \leq 0.001$ *****	$F_{1, 57} = 1.333$	$p \geq 0.05$	$F_{1, 11} = 0.044$	$p \geq 0.05$	$F_{1, 11} = 0.076$	$p \geq 0.05$
Annual precipitation	$F_{1, 57} = 20.35$	**$p \leq 0.001$ *****	$F_{1, 57} = 5.099$	**$p \leq 0.05$ ***	$F_{1, 11} = 0.468$	$p \geq 0.05$	$F_{1, 11} = 0.616$	$p \geq 0.05$
Precipitation of wettest month	$F_{1, 57} = 18.92$	**$p \leq 0.001$ *****	$F_{1, 57} = 2.068$	$p \geq 0.05$	$F_{1, 11} = 0$	$p \geq 0.05$	$F_{1, 11} = 1.756$	$p \geq 0.05$
Precipitation of driest month	$F_{1, 57} = 28.57$	**$p \leq 0.001$ *****	$F_{1, 57} = 19.96$	**$p \leq 0.001$ *****	$F_{1, 11} = 1.634$	$p \geq 0.05$	$F_{1, 11} = 0$	$p \geq 0.05$
Precipitation seasonality	$F_{1, 57} = 19.88$	**$p \leq 0.001$ *****	$F_{1, 57} = 7.52$	**$p \leq 0.01$ ****	$F_{1, 11} = 0.935$	$p \geq 0.05$	$F_{1, 11} = 0.078$	$p \geq 0.05$
Precipitation of wettest quater	$F_{1, 57} = 12.08$	**$p \leq 0.001$ *****	$F_{1, 57} = 1.785$	$p \geq 0.05$	$F_{1, 11} = 0.054$	$p \geq 0.05$	$F_{1, 11} = 1.306$	$p \geq 0.05$
Precipitation of driest quater	$F_{1, 57} = 25.79$	**$p \leq 0.001$ *****	$F_{1, 57} = 13.85$	**$p \leq 0.001$ *****	$F_{1, 11} = 1.649$	$p \geq 0.05$	$F_{1, 11} = 0.01$	$p \geq 0.05$
Precipitation of warmest quater	$F_{1, 57} = 20.18$	**$p \leq 0.001$ *****	$F_{1, 57} = 6.806$	**$p \leq 0.01$ ****	$F_{1, 11} = 0.704$	$p \geq 0.05$	$F_{1, 11} = 0.294$	$p \geq 0.05$
Precipitation of coldest quater	$F_{1, 57} = 0.634$	$p \geq 0.05$	$F_{1, 57} = 0.041$	$p \geq 0.05$	$F_{1, 11} = 3.127$	$p \geq 0.05$	$F_{1, 11} = 0.591$	$p \geq 0.05$

4 Discussion

4.1 Floral Composition and Plant Use in Gallery Forests

4.1.1 Diversity patterns

The analyses of gallery forest (GF) occurrence records identified in particular the southwest and also the southeast of Burkina Faso (BFA) as centres of GF diversity, especially in the provinces of Comoé, Houet and Tapoa (fig. 18). These patterns are in line with reported patterns of total species richness (Schmidt *et al.* 2017, Zizka *et al.* 2015a) and the expectations based on environmental conditions. In the southern part of BFA, the climate conditions are most suitable for forests (M. Schmidt *et al.* 2010) and GFs reach their largest extent (fig. 2 and 3). Accordingly, Guinko (1984) & Sambaré *et al.* (2011) have identified the GFs of the South Sudanian zone as most species-rich based on vegetation surveys.

The numbers of first species recordings in BFA (fig. 19) give an impression of the history of botanical exploration of the country and the potential of gallery forests (GFs) for the discovery of yet unrecorded species. Some interesting trends can be observed: the fluctuation of total collecting effort through time seems to be influenced by political frame conditions. There are pronounced dips in first species collections in the decades 1910-1920, 1940-1950 and 1980-1990 (see fig. 19) corresponding to the First and Second World War and the time of the socialistic revolution in BFA. The decreasing number of new records since the year 2000 might be due to an increased knowledge of the national flora achieved in the 1990ies, and the related higher efforts of finding new species. However, it could also be an artefact of the time-lag from specimen collection to identification and digitalization.

In general, the first recording of non-GF species (species not found in GFs) GF species (with documented occurrences in GFs) and GF specialists (only occurring in GFs) is similar through time. The only exception is the last decade, when the number of first recordings decreases for non-GF and GF species, but increases for GF specialists, suggesting GFs as potential habitat for yet undiscovered species. This might be due to the fact that GFs until today have been studied less than other habitats as a result of the vegetation often being dense and difficult to access. This applies especially to the south of BFA and where GFs therefore have attracted less collection effort. Indeed, species from GFs contributed a major proportion to a recent supplement of the national flora (César *et al.* 2009). Note however, that the absolute number of species of GF specialists is small (55 spp. compared to a total 307 GF species).

Only a small fraction of all specimens available from BFA is documented in GBIF and only for a fraction of these specimens the collection year is available. The numbers presented for first species recordings for BFA can thus only give a rough impression, and might be biased by collection activity. In particularly, by the activity of single expeditions or specific research institutions that contributed overproportionally to the dataset. From the approximately 4,600 specimens provided with a collecting date that were used in figure 19, the vast majority (91 %) was provided by only five institutions (Natural History Museum Paris and the herbaria of Wageningen, Aarhus, Kew and Leiden).

The results that GFs are the third most species-rich habitat and by far the most species-rich azonal habitat in BFA confirm the expectations (Natta 2003, Natta *et al.* 2002, Sambaré *et al.* 2011, Pither & Kellman 2002, Lykke *et al.* 1999). However, the magnitude of the importance of GFs discovered in this study was surprising. GFs potentially cover less than 1 % of the country area (calculated based on a 60 m buffer around the major river systems) but comprise about 15 % of all plant species known to the country. This extraordinary diversity might be linked to multiple factors associated with GFs as habitats. The increased water availability in the vicinity of rivers and the resulting habitat stability in an otherwise seasonal environment, in combination with regular, small scale disturbances by the rivers, are certainly important factors increasing species richness. Furthermore, the protection of GFs from frequent fires might be important. The savannas of BFA burn regularly and frequently (Schmidt 2006, Zwarg *et al.* 2012, Bocksberger 2012), favouring a relative specialized fire-adapted savanna flora and excluding fire-sensitive species (Higgins *et al.* 2000, Bond *et al.* 2005). The fires are mostly low-intensity groundfires not penetrating into GFs, making them a potential habitat for fire-sensitive species. Indeed, the species compositions of the GF flora shows increased species numbers for families generally not adapted to frequent fires (fig. 22).

A comparison of the species richness found in GFs with the existing literature stresses the importance of this habitat. Here, we identified 307 species constituting the GF flora of BFA, based on habitat information in Thiombiano *et al.* (2013), César *et al.* (2009) and on expert knowledge (K. Hahn, O. Sambaré, M. Schmidt, A. Thiombiano, A. Zizka, G. Zizka). Sambaré *et al.* (2011) found a total of 196 species in GFs in BFA based on 90 one ha sample plots throughout the country and Müller *et al.* (2012) found 133 GF species based on five vegetation transects in the Sudanian Zone in northern Benin. The much higher number of GF species identified here can be explained by the fact, that information about occurrence in GFs from the whole of BFA is combined. In agreement with the results presented here, vegetation surveys have shown that GF species diversity is not equally distributed throughout BFA (Sambaré *et al.* 2011). The species richness of GFs in a given area is mostly influenced by the zonal vegetation and the size of the river. The species richness of GFs roughly is of a similar magnitude as species richness in important protected areas in the Sudanian zone of Burkina Faso: Mbayngone *et al.* (2008a) found 450 plant species in the Reserve de Pama; Ouédraogo *et al.* (2011) found 490 species in the Arly National Park, both located in the southwest of the country; and Gnoumou *et al.* (2015) found 540 species in the partial faunal reserve of Comoé-Léraba in the southwest of BFA. The proportions are similar for the numbers of plant families: 64 families of GF species are documented in this study, fairly similar numbers are given for the total flora of the protected areas of Parma (73 families), Arly (83 families) and Comoé-Leraba (91 families).

GFs are not only particularly species-rich, but have also been shown to be taxonomically distinct communities (e.g. Guinko 1984, Müller *et al.* 2012). The particularity of GFs on family level was confirmed in the large-scale dataset of this study (fig. 22). While Fabaceae, a very diverse and cosmopolitan family, is the most species-rich family within GFs and the surrounding vegetation, other plant families are contributing overproportionally to the GF diversity: Rubiaceae, Acanthaceae, Apocynaceae, Moraceae, Vitaceae, and Phyllantaceae. An increased importance of Rubiaceae, Apocynaceae and Moraceae in GFs was also found by Müller *et al.* (2012). The importance of these families in GFs is most likely connected to the particular environmental conditions. For instance, Moraceae, Acanthaceae and Rubiaceae comprise species specifically adapted to forest environments. The family composition of the GFs is comparable to the composition in the protected areas in the Sudanian zone, and especially to the faunal reserve in Comoé-Léraba in that Rubiaceae, Apocynaceae, Acanthacea, Euphorbiaceae are more important than in the national flora, but differs in the reduced importance of Combretaceae, Poaceae and Cyperaceae (Mbayngone *et al.* 2008a, Gnoumou *et al.* 2015, Ouédraogo *et al.* 2011). The vegetation of these protected areas includes forests and woodlands but also savanna vegetation.

The shown taxonomical composition of GFs is reflected in the composition of life-forms of the flora. Phanerophytes and other woody growth form types as well as lianas are overrepresented in GFs, whereas therophytes are underrepresented.

Hemicryptophytes and geophytes are slightly less diverse in the GFs than in the surrounding savanna (fig. 21). The particular life-form composition can again be linked to the environmental conditions: increased competition for light, reduced water stress, and reduced fire frequency. The reduced fraction of therophytes is connected to the low number of Poaceae and Cyperaceae, which are mostly restricted to the open savanna habitat. The life form composition of GFs is also comparable to the Arly National Park in the most southern parts of the Sudanian zone, with phanerophytes as most important growth form (Mbayngone *et al.* 2008a, Gnoumou *et al.* 2015, Ouédraogo *et al.* 2011).

The taxonomic and functional similarities between the flora of GFs and the vegetation in protected areas in the South Sudanian zone at the southern border of BFA, stress the potential role of GFs as "range-extensions" and dispersal corridors northwards for species from climatically moister areas in the south of BFA.

4.1.2 Human plant use

Multiple factors might cause the high and specific importance of GF species for traditional human plant use (fig. 24). For some use types the reason is rather obvious: use for construction, tool production and firewood is most likely related to the higher percentage of tall woody species in GFs. Similarly, the reduced fraction of GF species used for animal fodder is likely associated with the reduced species richness and abundance of grasses in GFs, as grasses comprise the majority of plant species used for animal fodder.

The reasons for the overproportional importance of GF species in traditional medicine are less obvious. Environmental conditions such as water availability and soil properties have been linked to an increase in secondary metabolite content (Ziska *et al.* 2005, Melito *et al.* 2016), and also specifically with an increase in pharmacological activity (Björkman *et al.* 2011 and references therein, Maldonado *et al.* 2015). Thus, GFs might comprise more species with pharmacological active substances, or individuals with higher concentrations of pharmacological substances due to their particular environmental conditions. An alternative explanation is rather connected with socio-religious reasons. Local forests and GFs in the study area are often of special importance to local communities for religious reasons (Sène 2003, FAO 1990, Fairhead & Leach 1996). GF species might be preferred in traditional medicine because their occurrence is associated with religiously important sites. This explanation is, at least partly, supported by the observed increased importance of GF species for the use for religious and cultural purposes (fig. 24). Examples are *Berlinia grandiflora*, *Ceiba petandra* and *Ficus trichopoda*.

The increased importance of GF species for human nutrition, despite the reduced number of Poaceae species, might be connected to an increased presence of fleshy fruits in woody forest species (Zizka *et al.* 2015b, Bolmgren & Eriksson 2005). The fact that GF species are generally used in more different use categories might be attributed to the increase in large woody species which due to their higher biomass and various diverse anatomical structures can be employed for multiple purposes such as construction, firewood, and tool/craft production, but also nutrition and medicine.

In summary, the results presented on GF composition and traditional use show that the distinct functional and taxonomical composition of GFs compared with the surrounding vegetation, at least, partly explains the increased use of GF species in traditional plant use, and stresses the importance of these ecosystems for local communities. The large-scale approach used in this study is a valuable complement to the results of more localized floristic, phytosociological and ethnobotanical nature (e.g. Guinko 1984, Sambare *et al.* 2010). In particular, it has two important merits: 1) it includes a large number of species, among them range-restricted species and rare species that seldom occur in phytosociological, floristic or ethnobotanical studies, and 2) it enables a national scale estimation of the importance of GFs. However, there are also some caveats to this approach, which should be noted for the interpretation of the results: 1) the classification into habitats is to some degree arbitrary, especially the differentiation between "forest" and "GF" species; 2) No information of species abundance can be included; 3) Habitat information was only available for a restricted sample of species (1088 species/52 % of the total flora); 4) Local differences between traditional plant uses among ethnic groups or healers cannot be accounted for.

4.2 Distribution Range of Important Gallery Forest Species through Time

4.2.1 Distribution Models and Present-day Species Distributions

The strong influence of 'mean annual precipitation' and 'mean annual temperature' on the distribution of gallery forest (GF) species was expected. Burkina Faso (BFA) is situated on the fringe of forest distribution in West Africa and precipitation has been identified as the major factor influencing the distribution of forest species in the area (Bocksberger *et al.* 2016, Da 2010, Heubes *et al.* 2013). The reported importance of the 'minimum distance to the nearest major river' was expected, but was shown using modelling for the first time in this study, and confirms the role of water availability as key factor. The influence of this distance was particularly strong in the dry north of the study area in agreement with observations from the field (fig. 26 and 27). Individuals of the study species occurring in these areas are almost exclusively found in the immediate vicinity of a river, as otherwise conditions are too dry for large woody plants.

Despite the plausibility of the result, the influence of the river layer has to be interpreted with some caution, for three reasons: 1) differences in river size and permanence (seasonal vs. perennial) were not accounted for in the model. Perennial and temporary rivers or major streams and small tributaries were treated equally in the model once they were large enough to occur in the geographic gazetteer, whereas in reality the size and persistence of a river probably influences its significance for GF species; 2) Geographic changes in river structure since the LGM and climate influences on river characteristics were not accounted for when extrapolating through time. This is a simplification, because changes in precipitation will probably influence river size and presence; 3) the resolution of the distribution modelling was 30′′, equal to approximately one kilometre. Assuming the average GF width to be about 50 m on each side of the river, the resolution can be considered quite coarse for our purposes. I had to accept these limitations because there is no finer scale data available.

The modelled distribution of GF species in West Africa under recent climate conditions confirms patterns observed in vegetation and diversity in West Africa. The centre of suitable habitats for most GF species is in the Sudanian zone in south and central West Africa between 5° and 12° N. The longitudinal diversity patterns observed for West Africa cannot be explained. We assume them to be artefacts due to the selection of investigated species with their distribution centered in BFA (fig. 26C). The observed absence of 'potentially suitable habitats' (PSH) in the southwest of West Africa can be explained by the more humid conditions in this area enabling true rainforest vegetation with a different species composition. Whether the absence of GF species recorded from these areas reflects true climatic preferences or rather the outcome of biological competition with rainforest species remains elusive. The increase of predicted suitable habitat for GF species within the Dahomey Gap might have similar reasons. In contrast to other areas along the West African coast that are suitable for rainforest, the climatic conditions in the Dahomey Gap favour savanna and dry forest vegetation more suitable for GF species.

The maximum northwards extension of PSH to about 15° N in the western parts of the study area for some species (fig. 5A) might be related to the wetter climate in these areas compared to the eastern part of West Africa. The potential species richness of GF species in BFA reflects the importance of rivers for forest and GF species under the climatic conditions of BFA. BFA covers the fringe of forest occurrence in West Africa and the results clearly show the importance of river systems in expanding the potential distribution range of GF species into dryer areas (fig. 27).

4.2.2 LGM and Holocene

The modelling results indicate a strongly reduced area of PSH for GF species in West Africa during the Last Glacial Maximum (LGM). The remaining PSH at that time had shifted southwards to what today are the Guinean and South Sudanian zones (fig. 26A, Linder *et al.* 2012). The reduction of PSH for GF species, and the southwards shift are in agreement with the postulated general southward shift of the vegetation zones (Handiani *et al.* 2012, Anhuf 1997, Jacobs *et al.* 2010, Jolly *et al.* 1998, Dupont *et al.* 2000, Adams & Faure 1997) and the postulated decrease in forest cover and tree height in West Africa during the dry LGM conditions (Cowling *et al.* 2008). The areas of high GF species richness during the LGM agree with patterns in paleovegetation reconstructed for this time by Anhuf *et al.* (2006) and Anhuf (1997), who proposed persisting forests along the coast in eastern West Africa and more to the north in western West Africa including the highlands of Guinea (corresponding well with the area with > 10 GF species in fig. 26). The Guinea highlands have also been postulated as the sole rainforest refugium in West Africa by Maley (1991). The areas with higher GF species richness partly agree with the areas of higher forest cover during LGM in the very south of West Africa described by Cowling *et al.* (2008). The areas of high potential GF species richness during the LGM correspond to areas of high plant diversity found today by Linder (2001) and Barthlott *et al.* (2005). However, these areas do not correspond to areas of particular endemism or species with restricted range-size (Linder 2001, Küper *et al.* 2004). The areas with low projected GF species richness during the LGM along the southern coast of West Africa correspond well with the distribution of tropical rainforest remnants postulated by Ray & Adams (2001) and Anhuf (1997). In agreement with the above cited reconstructions of species distribution at the LGM, the models of this study do not project any PSH for GF species in the area of current day BFA during the LGM. This suggests that no major habitat for forest species remained in the area, rejecting the hypothesis of GFs as *in situ* refugia for forest species in BFA. However, the possibility of micro-refugia in areas especially favoured by topography and microclimate during the LGM cannot be ruled out, but there is currently no evidence supporting such microhabitats in our data or in the literature.

In summary, the modelled strong retractions of GF species distributions during LGM climate conditions are consistent with prevailing ideas of vegetation zone contractions and a southwards shift of forest vegetation due to drier conditions. Areas of potential refugia for GF species correspond to areas with reconstructed dry forest rather than rainforest.

Less information is available on the climate and vegetation structure in West Africa during the mid-Holocene climate optimum. In general, the increase of PSH during this time compared to the LGM reported here, meets the expectations. The considerable northwards shift of GF species habitat (fig. 26) is consistent with wetter climate (Jolly *et al.* 1998), and the results of Anhuf (1997) proposing a considerable northwards extension of dry forests up to 19 degrees north in central West Africa during the mid-Holocene optimum. The projected high GF species richness in the area of the Dahomey Gap is consistent with hypothesis of a closure of the Dahomey Gap by forest vegetation during the mid-Holocene (Salzmann & Hoelzmann 2005). These authors also observed a strong increase in the pollen of the genus *Uapaca* in the area of today southern Benin at the time of the mid-Holocene optimum, consistent with the increase of PSH for the GF species *Uapaca togoensis* reported here (supplementary material available at the Zenodo repository (doi:10.5281/zenodo.376190)).

4.2.3 Climate Change and Future Conditions

The distribution models indicate a negative correlation between the per species increase of PSH under future climate conditions and the importance of precipitation variables in the distribution model. This suggests that the stronger a species' distribution is influenced by precipitation, the less increase of PSH for this species was predicted. Similarly, the predicted increase of PSH was positively correlated with the importance of temperature and river vicinity in the models. This suggests that the more the distribution of a species is influenced by temperature and rivers the larger the habitat expansions for this species.

The areas of strongest GF species richness increase are close to rivers (fig. 26), stressing the importance of rivers for GF species in West Africa and Burkina Faso under future climate conditions. The results have to be interpreted with caution, as the effects of a potential change in precipitation on river size and seasonality were not included in the model. Changes in water availability might affect river extent and size (Delire *et al.* 2008) in a way that rivers might fall dry or turn from permanent to seasonal rivers or *vice versa*, with considerable consequences for the suitability of their bank as habitat for GF species. The observed strong effect of river distance for GF species richness under future climate conditions was an important result of this study, stressing the increased importance of rivers as water supply, particularly in those areas of West Africa with a projected decrease in precipitation-where climate conditions become drier and thus less suitable for forest.

The magnitude of the projected increase in PSH under future climate conditions was unexpected. The climate data used in this study was dereived from the RCP 4.5 scenario of the AfriClim-Ensembles model. Future climate from this scenario is widely used as plausible on a global scale. It projects a slight increase in precipitation for most parts of West Africa. However the projected change was mostly moderate (MAP median per grid cell change: +9.9 mm, or +1.8%) and larger changes were mostly confined to costal areas. Therefore, an increase in PSH was expected, but the magnitude off this effect was surprising. The strong increase in PSH might be related to interactions between the precipitation increase and the water supply by rivers (as represented by the 'minimum distance to the nearest major river' layer), which together might critically increase habitat suitability for GF species. There is a considerable amount of uncertainty related to these results, due to the uncertainties in climate projections for the region. Future precipitation is difficult to predict, much more so than temperature (Hawkins & Suttons 2010, Deser et al 2010), especially in West Africa (Druyan 2010, Paeth et al 2011, Alo & Wang 2010). Thus it is a matter of ongoing debate, if the precipitation in the region will increase (Niang et al 2014, Paeth et al 2004; Vizy et al 2012) or actually decrease (James & Washington 2013, Patricola & Cook 2011, Cook & Vizy 2004). In any case, drier conditions might be probable in at least some areas of the region (Druyan 2010).

The uncertainty in climate change prediction is also eminent in the scientific debate on the impact of climate on the vegetation of West Africa, where a negative impact of climate (Sommer *et al.* 2010) as well as an increase of forest cover in the 21st century seems possible (Heubes *et al.* 2011). The development of the vegetation in the Sudanian zone and especially the Sahel in West Africa has been discussed controversially in the scientific literature. Tree census data from dry periods in West Africa between 1940 and 2000 show that under dry conditions forest species richness and tree density decrease, and vegetation zones shift southwards (Gonzalez 2001). Furthermore, Heubes *et al.* (2013) found a negative impact of climate and land-use for the flora of Burkina Faso until 2050, predicting an average loss of 24 % of the species per 0.1 degree grid-cell in Burkina Faso, with much higher rates up to 60 % loss in the south of the country, where most GF species occur (fig. 18). These authors also find the adverse effect of climate to be stronger than the effect of land-use. Accordingly, regional (McClean *et al.* 2005) and global models (Sommer *et al.* 2010) find a strong decrease in potential species richness for entire West Africa under climate change. Additionally, Wittig *et al.* (2007a) found an increasing southwards shift of Sahelian and Sudanian vegetation due to the combined impact of precipitation decrease and human land-use intensification. Furthermore, Wezel & Lykke (2006) report a population size decrease for 80 % of woody plant species in a case study in BFA, Niger and Senegal. Delire *et al.* (2008) revealed a retraction of forest and a reduction of total tree cover together with a southwards shift of vegetation zones in West Africa, so that only the most south-western parts of BFA could sustain forests at the end of the 21st century. In contrast, a greening of the Sahara and the Sahel has been observed since the end of the 20th century (Eklundh & Olsson 2003, Herrmann *et al.* 2005), and also been projected for the 21st century (Heubes *et al.* 2011). This effect has been attributed to precipitation effects, human land-use, and increased CO_2 concentration in the atmosphere (Hickler *et al.* 2005, Olsson *et al.* 2005, Donohue *et al.* 2013). The anthropogenic caused increase of CO_2 concentration together with increasing temperature is highly probable to induce an increase in woody plant biomass and land cover, in particular in West Africa (Higgins & Scheiter 2012, Scheiter & Higgins

2009). Plants with C3 photosynthesis (including the vast majority of woody plants) benefit from increased CO_2 concentrations, as these increase their water use efficiency and gives them a competitive advantage over C4 plants (most grasses in the region). Thus higher CO_2 concentrations might further increase postive effects of increasing precipitation or outweigh negative effects of decreasing precipitation and increasing temperature (this effect was not included in the models of this study). Even without these CO_2 fertilization effects, a Sahel greening with northwards expanding forests, based on climatic changes has been proposed for West Africa in the 21st century (Heubes *et al.* 2011).

While the effect of climate on West Africa vegetation remains debated, it is likely that human land-use change will have negative impacts for vegetation and diversity in the region, and in BFA in particular (Heubes *et al.* 2013, Sala *et al.* 2000, Geist & Lambin 2004, König *et al.* 2007). The expected strong decrease of available habitat due to increasing human population and intensification of agriculture, might easily outweight potential stimulating effects of climate change (if there are any). BFA is a developing country, with large annual population growth rate and an expected increase in land-use intensity, in particular for non-subsistence agriculture (Baudron *et al.* 2009, The World Bank Group 2016). GFs are in particular endangered by land-use change, as they are especially sensitive to changes in water level and thus to impacts like irrigation and dam construction (Sambaré *et al.* 2011). Adverse effects from land-use intensification will most likely substantially decrease PSH and range size for GF species. In any case, strong efforts are necessary to conserve the remaining GFs.

In summary, the PSH for GF species has constantly increased since the LGM, mostly in form of a northwards extension (fig. 25 and 26). The increase and its spatial direction fit the expectations from previous studies, and show that GF species follow general vegetation and forest trends, tracking increasing precipitation. The slight (non-significant) increase in PSH between the mid-Holocene and current climate conditions, suggests only minor differences between these two times. For future climate conditions the results of this study are in line with a greening trend in West Africa and Burkina Faso and suggest that climate changes will not constitute a major threat to GF species in the region. The vicinity to rivers, and the related water supply emerged as a crucial factor for the positive habitat projections for GF species, but uncertainty is high. Change and intensification of human land-use are the major threats to GF species, as probably it is to global biodiversity as a whole.

4.3 Gallery Forests as Refugia

4.3.1 Genetic Structure and River Basins

All analyses of genetic population structure in this study agree in three fundamental points: 1) There is a consistent population structure and genetic differentiation between the populations across all study species, but with considerable amount of admixture (fig. 32 and 36, table 3); 2) There is a geographic element in the genetic structure (fig. 33, 34 and 37), but this is not connected to river basins (fig. 35); 3) Genetic patterns are not related to seed dispersal mode and not correlated with the degree of dependence on water availability. The identification of genetic structure in a species is a major tool in phylogeography (e. g. Avise 2009, Schaal *et al.* 1998). The existence of genetic structure in a group of organisms indicates the presence of factors limiting gene-flow within this group. Limited gene-flow is a prerequisite for speciation as well as for genetic and functional diversification. Linking observed genetic structure to external factors from geography, ecology or biogeographic history, allows inference on the drivers of speciation and diversification, contributing to our understanding of evolution of life and its mechanisms.

Phylogeographic studies in West Africa are scarce, especially for plants. Dodd *et al.* (2002) found a relative high genetic diversity within *Avicennia germinans,* a river estuary and coast bound mangrove tree, in West Africa compared to other parts of the global distribution range. Furthermore, these authors reported a significant importance of long-distance dispersal between Africa and North America in this species. Assogbadjo *et al.* (2006) found F_{ST} values comparable to the ones reported in this study (see table 3) for populations of Baobab (*Adansonia digitata*) across West Africa. In this case, isolation by distance was identified as major driver of genetic differences. The same authors found generally lower F_{ST} values (up to 0.23) in Baobab populations in Benin. On an African scale, Allal *et al.* (2011) found F_{ST} values of around 0.21 for *Vitellaria paradoxa* based on microsatellites, with a relatively low intra-specific diversity in West Africa. These authors accounted the genetic structure found in these species predominantly to LGM refugia. Generally, phylogeographic analyses have shown West African tree species to be genetically distinct from populations in Central and East Africa and to be genetically more variable than in these other parts of Africa (Pock Tsy *et al.* 2009, Karan *et al.* 2012, Odee *et al.* 2012). The F_{ST} values reported in this study (see table 3) are in the range of values expected for outcrossing species (Nybom & Bartish 2000). Many tree species are known to show a relative high within-population genetic diversity, and a relatively modest one among populations, possibly due to high levels of pollen flow and multi-generation populations (Austerlitz *et al.* 2000, Assogbadjo *et al.* 2006). This has also been found on geographic scales similar to this study in West Africa (Assogbadjo *et al.* 2006).

Geographic barriers are a widely accepted explanation causing and maintaining genetic population structure (e.g. Taberlet *et al.* 1998), by preventing or significantly hampering species dispersal. Examples for typical geographic barriers are oceans, mountain chains, rivers or deserts. Genetic structure observed in recent organisms can also be the consequence of past, but no longer existent barriers. For West African Gallery forest (GF) species, the extended savanna vegetation between different GFs might constitute a significant barrier to gene flow. GF species often do not thrive in ordinary savanna vegetation and therefore are often restricted to the immediate vicinity of the river system (see sections 1 and 1.1). This might also be true for their usually forest living pollinators and seed-dispersers. This effect could lead to a genetic structure correlated to river catchment basins, as species predominantly mate and disperse within the continuous forest along the interconnected rivers of a catchment basin. Such a genetic population structure related to river catchment basins has been reported from West African fish, that (in a very broad sense) might be comparable to some GF species in their limitation by dispersal barriers in the West African landscape (Durand *et al.* 2005).

The results of this study do not support this hypothesis of river catchment basins as important structuring element in GF populations. The genetic structure of all study species does not correspond with catchment basins, but rather represents an east–west split in the study area with scattered individuals of all populations distributed throughout the study area (fig. 33, 34 and 37). A genetic east–west differentiation in tree species has been reported repeatedly on an African scale (Pock Tsy *et al.* 2009, Karan *et al.* 2012, Odee *et al.* 2012) and a genetic split into eastern and western populations throughout Burkina Faso (BFA) has been observed in animals (Brouat *et al.* 2009, Dobigny *et al.* 2013). The east-west split in GF species might be related to re-colonization history after LGM (see section 3.2) or to ecotypes adapted to different environmental conditions. Genetically isolated individuals in the populations can be explained by long-distance dispersal, as has been observed in other West African trees (Dodd *et al.* 2002, Dick *et al.* 2007). The absence of any relation between river catchment basin geography and the genetic structure of GF species was not expected, but related results have been reported before by Leal

(2004). In a study based on vegetation similarity index this author rejected rivers as dispersal corridors for plant species range extensions in West Africa. The reasons for the independence of genetic population structure in the study species and river catchment basin geography remain unclear, but there are several possible explanations: 1) Savannas might not be as strong dispersal barriers to GFs as expected. High capacity for long distance dispersal events have been reported for West African tree species (Dodd *et al.* 2002, Dick *et al.* 2007). An increased capacity for dispersal might also be common in West African forest species as the Pleistocene dry and wet cycles might have selected for species with high dispersal capacity. All the investigated GF species are good dispersers, as they had to be in the past. Moreover, the study species are not entirely confined to GFs and can occur in other more humid micro habitats in savannas, and different river catchments might therefore be linked through "stepping stones" in the savanna habitat. 2) Anthropogenic dispersal might have overwritten the signal of natural dispersal barriers (Levis et *al.* 2017). Human influence on West African vegetation has been strong for thousands of years and a strong human influence on genetic population structure has been found for Baobab (*Adansonia digitata*) (Houehanou *et al.* 2013, Kyndt *et al.* 2009) and has also been suggested for *Vitellaria paradoxa* (Lovett & Haq 2000). These two species are heavily used, which makes them particularly prone to a strong anthropogenic imprint on population structure. However, a similar, but weaker influence could be possible for GF species, as at least some of them are also heavily used (see section 3.1). 3) River catchment structure might be important on a smaller geographic scale. The river catchment model used in this study was relatively coarse, and possibly a more complex model would be needed to detect the influence of rivers on genetic population structure. This could invoke smaller scale geographic units, such as single rivers instead of catchment basin or the inclusion of temporal changes in connectivity between GFs and river basins during different climate conditions in the past.

Pleistocene refugia are commonly used to explain the biogeographic history and observed genetic population structure in African rainforest trees (Allal *et al.* 2011, Duminil *et al.* 2013, Duminil *et al.* 2015), savanna trees (Allal *et al.* 2011), and also in forest and savanna animals (Anthony *et al.* 2007, Bertola *et al.* 2011, Barlow *et al.* 2013, Brouat *et al.* 2009, Lorenzen *et al.* 2007, Lorenzen *et al.* 2012). The results of the population genetic study presented here show no signal to characterise GFs as refugia or dispersal corridors during past climatic oscillations in BFA. This is supported by the results of the species distribution modelling (chapter 2), where large areas of West Africa are indicated as unsuitable for GF or forest species during the LGM, despite the presence of rivers. Thus the role of GFs as refugia and dispersal corridors seems to be more complex than assumed, possibly due to the dynamic nature of river systems.

There was no link between genetic population structure and dispersal mode of the GF species as well as specialisation in the GF habitat. This might be further evidence for the hypothesis that all GF species are "good" dispersers due to the history of climatic fluctuations. A weak influence of isolation by distance was suggested for *Paullinia pinnata*. This species is dispersed by birds and mammals, quite similar to *Diospyros mespiliformis* (dispersed by baboons and other mammals). *Pterocarpus santalinoides*, which is dispersed by water (and therefore should show a correlation between geographic and genetic distance) displays no clear pattern as well. The dispersal mode does not seem to have an influence on the genetic structure in any of the study species.

AFLPs are a widely used and generally reliable, cheap and high-resolution tool to investigate genetic structure on the population and individual level. They are commonly and widely used in ecology and evolution, especially on shallow timescales (Bensch & Åkesson 2005, Meudt & Clarke 2007). However, they have some caveats (Nunes *et al.* 2012) and sporadically have been reported to be sensitive to artefacts from sampling and laboratory protocols. In this study the AFLP results were controlled analytically for such artefacts: the correlation between genetic clusters and collection date, DNA extraction date and enzyme digestion date were checked and did not shown irregularities. Peak scoring was also double-checked manually as described in the methods section. Therefore, artefacts caused by the AFLP method can be excluded as cause of the observed structure, with reasonable confidence.

In summary, the results of this study do not support GFs as local refugia or dispersal corridors for forest species in BFA. The geographic population structure might be rather related to a regional scale re-colonization pattern or possibly to human influence. The results suggest "long distance" dispersal as common feature in GF species, irrespective of specific dispersal mechanisms. The results fit with some similar observations made in other taxonomic groups of plants and animals.

4.3.2 Environmental correlation

In three out of four study species the genetic structure was not correlated to geographic distance, and the observed correlation in *Paullinia pinnata* was only weak. The results were independent of dispersal mechanism, thus dispersal limitations do not seem to contribute significantly to the genetic structure of the investigated GF species in BFA. The independence of genetic structure from geographic distance differs from results reported for *Adansonia digitata* (Kyndt *et al.* 2009, Assogbadjo *et al.* 2006). This could be related to the fact that long distance dispersal, either via rivers or animals was more common in the study species than in *A. digitata*, or to the relatively smaller geographic extent of this study (restricted to BFA). As the genetic data show a consistent clustering in three populations for all species, the question remains which factors other than geographic barriers or geographic distance could cause such a structure. Adaptation to environmental conditions under selective pressure can cause and conserve genetic population structure in the absence of geographic barriers (Bragg *et al.* 2015, Vitti *et al.* 2013). Adaption to climatic and edaphic variables has been shown to be influential on genetic population structure and speciation (Paun *et al.* 2016, Forester *et al.* 2016). Indeed, genetic clustering in the study species was correlated with edaphic and climatic variables. 'Mean annual temperature' and 'mean annual precipitation' were identified as significant factors across all study species. Interestingly, these are also the environmental factors dominantly shaping the distribution of species as shown in section 3.2 of this thesis. The correlation between environmental variables and genetic population structure suggests ecotypes adapted to particular environmental conditions. That is in agreement with findings of correlations between climate and genetic structure in *A. digitata* in Benin (Assogbadjo *et al.* 2006) and Africa-wide patterns in *Erythropleum* spp. (Duminil *et al.* 2013). The observed genetic clusters might reflect different ecotypes rather than different dispersal histories, indicating influence of selection and potentially ongoing ecological speciation.

The methods and data applied here have some limitations. Most critical are the sampling (very much influenced by the accessibility of GFs) and the precision of the edaphic and climatic variables. The exact role of environmental conditions for the observed genetic structure needs more research and potential drivers remain elusive. However, the results are promising and further studies combining sampling of morphological and physiological traits, small-scale climatic and edaphic conditions with DNA sampling offer an interesting approach to explore this topic further. In particular, as new molecular biological methods and statistical approaches for detecting influence of selection and adaption to environmental factors on genetic population structure have recently become available (De Mita *et al.* 2013, Forester *et al.* 2016, Rellstab *et al.* 2015).

4.3.3 Species-Tree Diffusion Models

The species distribution models indicated no suitable habitat for the study species in BFA during the LGM, suggesting no refugia for forest species in the area. A major question emerging from this result (see section 3.4) is how the study area has been recolonized in the relatively short time span since the LGM. Interestingly, the species-tree diffusion models for all four study species agree in major points, suggesting: 1) re-colonization from the south of the study area, 2) an early split in relatively isolated western and eastern populations and 3) an increased undirected dispersal in recent times.

The results confirm a re-colonization of BFA from the south, which seems the only plausible option based on our knowledge of paleoclimate and -vegetation. The early split into an eastern and western population is puzzling. An explanation of this pattern could be related to the geographic position of Burkina Faso northwest of the Dahomey Gap (fig. 7 and 10C). Potentially, the observed split might be related to different recolonization sources. In this scenario the eastern parts of BFA might have been recolonized from populations east of the Dahomey Gap, whereas populations in the west of BFA might have been more closely related to populations west of the Dahomey Gap. Potential refugia during LGM climate could have been in the south of Benin and Nigeria for the east and the south of Cote d'Ivoire and Liberia in the west (see section 3.2). This exciting, but fairly speculative, scenario could be tested by extending the sampling geographically and also taxonomically, including genetic samples from the areas south of BFA and the potential refugia. The consistency of the pattern in the four study species suggests the existence of a cross-taxonomic pattern indicating a possible general pattern in the historical biogeography of West African forests: a differential re-colonization of northern West Africa with forest species from separate refugia in the west and the east of the Dahomey Gap.

A potential scenario explaining the observed increase in erratic dispersal in recent times could be related to human activity. Humans have been present in West Africa for thousands of years, but their impact on vegetation and plant dispersal increased through time. To elaborate on such a potential anthropogenic influence an absolute dating of the results from the species-tree diffusion modelling would be important. Absolute dating of AFLP data has been tried (Kropf *et al.* 2009), but has proven difficult and been criticized heavily (Ehrich *et al.* 2009), so that additional sequence data, ideally from across West Africa would be necessary.

The species-tree diffusion models used here are a relatively new approach towards a continuous historical biogeography overcoming discrete area classification (Nylinder *et al.* 2014, Quintero *et al.* 2015). The approaches are promising, but currently suffer from some limitations, mainly related to the assumptions of a Brownian motion process. Specifically, the models assume an equal dispersal through space. In the case of GFs and the potential restriction of forest species to rivers as small dispersal corridors, this is an obvious simplification. Methods for the inclusion of paleoclimate data are currently being developed (S. Nylinder, pers. communication) and will potentially increase the power of species-tree diffusion models to improve our understanding of the historical biogeography of West African GFs.

4.4 Conservation of Gallery Forests

The results of this study stress gallery forests (GFs) as diverse and unique habitats, peculiar in their composition of species and functional types and contributing over-proportionally to the national biodiversity of Burkina Faso (BFA). Additionally, GFs are of particular interest to the human population, providing specific and rich resources for plant use and being of special religious and sociological importance. At the same time GFs in BFA face severe human land-use pressure and are considered particularly threatened (e.g. Sambaré *et al.* 2011). This thesis used genetic and phylogeographic approaches to improve our understanding of the historical and recent biogeography of GFs. A remaining overarching question is how the results presented can help to document biodiversity changes in GFs and to improve GF conservation. One of the major goals of comprehensive and effective conservation is to maximize the protection of multiple dimensions of biodiversity, including taxonomic, genetic and functional diversity and to minimize extinction risk. There are multiple approaches to conservation, including site-based approaches, trying to conserve particular habitat or ecosystem types (Myers *et al.* 2000, Eken *et al.* 2004) as well as species-based approaches trying to assess the extinction risk and conservation value of individual species (Isaac *et al.* 2007, IUCN 2015). A site-based approach can focus on maximizing one or multiple biodiversity metrics such as species richness, endemism, phylogenetic diversity, functional diversity or genetic diversity (Faith 1992, Faith *et al.* 2004, Moritz & Faith 1998).

A widely used tool for species-centred conservation is the extinction risk assessment based on the red lists of the 'International Union for the Conservation of Nature' (IUCN 2015), which use a set of standardized criteria, including population size, population decline, abundance and range size to assess the extinction risk of a species (IUCN 2012, IUCN Standards and Petitions Subcommittee 2016). The 'extent of occurrence' (EOO) and the 'area of occupancy' (AOO) are indices to assess extinction risk under criterion B of the IUCN red list. AOO and EOO alone are not sufficient to classify species in their IUCN framework, and other parameters such as habitat loss and population decline should be included in the assessment. In the framework of this study EOO and AOO show a rather low extinction risk for all GF study species. All study species have wide distribution ranges throughout large parts of West Africa, making them less susceptible to extinction by local threats. Furthermore, the AOO shows that most species occupy substantial parts of their distribution range. The AOO assessments are more conservative than EOO for the study species, but numbers are still relatively high compared to other species of the region (Schmidt *et al.* 2017) and will potentially increase substantially with increasing sampling. Some inference on the threat of the species by climate change can be made from the distribution models. The models for West Africa suggest that climate change might not be the major threat to GF species as the potentially suitable habitat is projected to increase for most species (under the limitations discussed above). This is encouraging and puts the focus on threat through human land-use, which has the potential for disastrous effects on GFs. In summary, based on range size and habitat preferences, the results of this study suggest that key GF species in West Africa are potentially resilient to small scale threats and moderate climate change on the regional scale. However, a comprehensive IUCN assessment for the study species is an important next step, for informed conservation efforts.

On the national level the high species richness and the particular taxonomic and functional composition (see section 3.1) confirm GFs as high priority habitats for conservation. A national scale perspective to conservation is of high interest, as in the region the majority of relevant conservation authorities are nationally organized. In Burkina Faso, most of GF species are restricted to the southern parts of the country (fig. 18). Additionally, most species are confined to a very small portion of their range size to habitats along the river banks (fig. 27) making most species susceptible to local extinction if these habitats are cleared for human land-use (Sambaré *et al.* 2011). The distribution modelling again suggests that moderate climate change might not be the most severe threat for GFs in BFA. However, if climate should approach LGM conditions, which is within the possible range of scenarios for the 21st century, history suggests that climate might no longer support GFs in Burkina Faso, which then will lead to a substantial loss of national biodiversity. Under the moderate climate change scenario, the major threat for GFs is human land-use pressure. The adverse effects of increased human land-use are manifold and span from direct clearings for agriculture or wood extraction to more indirect effects like changes in river water level due to dam construction or irrigation (Sambaré *et al.* 2011). Encouragingly these effects can be addressed by focused, national conservation effort.

In summary, under a moderate climate change, conservation effort focusing on the restriction of human land-use might be effective in conserving GFs in BFA. Additionally, the indicated high genetic admixture between the GF populations within the country is encouraging for a potential conservation of genetic diversity via the conservation of strategically chosen GF areas that can include a substantial portion of the total national genetic diversity (fig. 33-37).

4.5 Remarks on the Study Species

Anogeissus leiocarpa is a morphologically and ecologically plastic species with a very large distribution range from West to East Africa, and a broad ecological amplitude, spanning from the humid Guinean zone to the arid Sahel in West Africa (Aké Assi 2001, Couteron & Kokou 1997, Thiombiano *et al.* 2006). It is the most drought tolerant gallery forest (GF) species, often the only species constituting GFs in the north of Burkina Faso (BFA). *A. leiocarpa* was included in this study as a generalist species also occurring in GFs rather than as a GF specialist. This "generalist" ecology of *A. leiocarpa* (and *also Diospyros mespiliformis*) is reflected in its modelled distribution range, which differs from the projected distributions of most other GF species in that it includes much drier areas. These results match the personally observed distribution in the field. In the context of the large distribution range and the wide ecological amplitude the high impact of the 'minimum distance to the nearest major river' layer in the species distribution model was unexpected. The suggested strong dependence on rivers might be due to the occurrence of this species in relative dry areas, where it is confined to riversides. A potential adaptation of *A. leiocarpa* enabling the species to colonize dry habitats could be its high morphological variability and the species ability to switch to asexual reproduction under unfavourable environmental conditions (Kambou 1997, Bognounou *et al.* 2010, Ouédraogo *et al.* 2013). There are no particular concerns on the conservation of *A. leiocarpa*, due to its large distribution range (second largest EOO of all study species), the relative high AOO, the projected increase in 'potentially suitable habitat (PSH)' due to climate change and a demonstrated resilience to anthropogenic disturbances (Ouédraogo *et al.* 2013).

Diospyros mespiliformis is known to be a generalist species with large ecological amplitude, not particularly bound to GFs. This makes the strong increase in PSH for this species suggested by the distribution models plausible. There are no particular concerns on the conservation of *D. mespiliformis*, due to its large distribution range (highest EOO in West Africa) and the high abundance (highest AOO of all study species).

Paullinia pinnata is a climbing species widely distributed throughout tropical and subtropical Africa. The distribution models showed an average response of the species to climate factors and a strong increase of suitable habitat under future climate conditions, both of which were characteristic for the majority of GF species included in these analyses. The species is not of particular concern for conservation as EOO and AOO are relatively large.

Pterocarpus santalinoides is generally considered to be bound to the immediate vicinity of rivers and to only occur on humid soils. Hydrochorous dispersal has been hypothesized as important dispersal mechanism in this species (Arbonnier 2002). Generally, the species is considered to be strongly linked to water courses, which makes the intermediate influence of the 'minimum distance to the nearest major river' in the modelling of this study unexpected. A possible explanation could be found in the coarse resolution of the study. Compared to other GF species, *P. santalinoides* is not of particular concern for conservation, due to its moderately sized distribution range and its high AOO. This reflects the fact that the species is restricted to the Sudanian and Guinean vegetation zones, but is quite abundant in these zones.

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8 Annex

9.1 List of Genetic Samples

This supplementary material shows all individuals of the four main study species used for genetic analyses with their sample ID, coordinates, collection date, collector and the river basin they belong to.

Species	Sample ID	Lat	Long	Date	Collector	River basin
Anogeissus leiocarpa	Anogeissus_06	9.9135	-4.6261	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_07	9.9135	-4.6256	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_08	9.9137	-4.6252	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_05	9.9301	-4.6190	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_04	9.9315	-4.6087	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_09	10.6171	-5.4170	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_65	10.6196	-5.4244	30.09. - 03.10.2010	S. Porembski	West Coast
Anogeissus leiocarpa	Anogeissus_66	10.6478	-5.0352	30.09. - 03.10.2010	S. Porembski	West Coast
Anogeissus leiocarpa	Anogeissus_64	10.7083	-4.8144	30.09. - 03.10.2010	S. Porembski	West Coast
Anogeissus leiocarpa	Anogeissus_58	10.7220	-4.8207	30.09. - 03.10.2010	S. Porembski	West Coast
Anogeissus leiocarpa	Anogeissus_01	10.7221	-4.8207	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_02	10.7221	-4.8207	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_03	10.7225	-4.8211	09.06. - 02.07.2009	I. Kirchmair	West Coast
Anogeissus leiocarpa	Anogeissus_60	10.7233	-4.8220	30.09. - 03.10.2010	S. Porembski	West Coast
Anogeissus leiocarpa	Anogeissus_62	10.8196	-4.8202	30.09. - 03.10.2010	S. Porembski	Volta
Anogeissus leiocarpa	Anogeissus_61	10.8233	-4.8223	30.09. - 03.10.2010	S. Porembski	Volta
Anogeissus leiocarpa	Anogeissus_85	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_86	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Anogeissus leiocarpa	Anogeissus_87	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_55	11.0972	-0.7078	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_56	11.0977	-0.7080	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_57	11.0985	-0.7080	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_68	11.1531	-4.1950	30.09. - 03.10.2010	S. Porembski	Volta
Anogeissus leiocarpa	Anogeissus_11	11.1890	-4.4429	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_10	11.1892	-4.4423	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_88	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_53	11.2791	-1.9281	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_52	11.2791	-1.9277	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_54	11.2793	-1.9283	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_82	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_84	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_106	11.4386	-1.1774	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_49	11.4389	-1.1803	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_50	11.4398	-1.1797	09.06. - 02.07.2009	I. Kirchmair	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Anogeissus leiocarpa	Anogeissus_101	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_102	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_16	11.5473	-4.1092	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_17	11.5482	-4.1096	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_18	11.5604	-4.1408	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_19	11.5608	-4.1414	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_20	11.5613	-4.1413	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_79	11.5693	0.5317	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_80	11.5693	0.5317	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_81	11.5693	0.5317	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_76	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_77	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_100	11.6066	2.0206	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Anogeissus leiocarpa	Anogeissus_15	11.6544	-4.4637	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_13	11.6666	-4.4615	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_12	11.6673	-4.4617	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_71	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_72	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_73	11.6807	2.2284	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_74	11.6807	2.2284	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_75	11.6807	2.2284	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_51	11.7789	-1.6019	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_104	12.3216	1.6633	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_48	12.4426	-1.3534	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_108	12.4428	-1.3531	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Anogeissus leiocarpa	Anogeissus_109	12.4428	-1.3531	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Anogeissus leiocarpa	Anogeissus_21	12.5055	-3.5538	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_22	12.5056	-3.5539	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_29	12.5167	-3.2546	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_27	12.5168	-3.2547	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_28	12.5168	-3.2547	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_30	12.5170	-3.2531	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_26	12.6439	-3.4628	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_24	12.6442	-3.4644	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_25	12.6442	-3.4644	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_23	12.7511	-3.4274	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_46	12.7527	-1.1533	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_45	12.7530	-1.1529	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_47	12.7530	-1.1534	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_44	13.2006	-1.1393	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_31	13.8361	-2.0329	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_32	13.8859	-1.9247	09.06. - 02.07.2009	I. Kirchmair	Volta
Anogeissus leiocarpa	Anogeissus_43	13.8981	-1.6536	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_42	13.8986	-1.6540	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_41	13.8988	-1.6539	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_35	14.2207	-1.5440	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_36	14.2215	-1.5430	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_37	14.2219	-1.5431	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_38	14.2826	-1.4675	09.06. - 02.07.2009	I. Kirchmair	Niger
Anogeissus leiocarpa	Anogeissus_40	14.2828	-1.4668	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_10	9.8529	-4.6142	09.06. - 02.07.2009	I. Kirchmair	West Coast

Species	Sample ID	Lat	Long	Date	Collector	River basin
Diospyros mespiliformis	Diospyros_08	9.9146	-4.6253	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_07	9.9301	-4.6190	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_06	9.9306	-4.6186	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_05	9.9319	-4.6086	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_03	10.2624	-4.8858	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_02	10.2629	-4.8858	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_04	10.2634	-4.8860	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_56	10.6835	-5.1934	30.09. - 03.10.2010	S. Porembski	West Coast
Diospyros mespiliformis	Diospyros_01	10.7218	-4.8204	09.06. - 02.07.2009	I. Kirchmair	West Coast
Diospyros mespiliformis	Diospyros_55	10.7241	-4.8223	30.09. - 03.10.2010	S. Porembski	West Coast
Diospyros mespiliformis	Diospyros_58	10.9286	-4.4928	30.09. - 03.10.2010	S. Porembski	West Coast
Diospyros mespiliformis	Diospyros_86	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_87	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_11	11.1881	-4.4415	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_12	11.1898	-4.4420	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_13	11.1898	-4.4420	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_88	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_89	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	**Sample ID**	**Lat**	**Long**	**Date**	**Collector**	**River basin**
Diospyros mespiliformis	Diospyros_90	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_83	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_84	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_85	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_53	11.4381	-1.1787	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_91	11.4386	-1.1774	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_92	11.4386	-1.1774	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_54	11.4389	-1.1803	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_70	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_71	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_17	11.5486	-4.1098	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_18	11.5486	-4.1096	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_19	11.5486	-4.1096	09.06. - 02.07.2009	I. Kirchmair	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Diospyros mespiliformis	Diospyros_80	11.5693	0.5317	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_81	11.5693	0.5317	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_82	11.5693	0.5317	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_75	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_76	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_77	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_20	11.5985	-4.1296	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_21	11.5986	-4.1296	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_22	11.5991	-4.1301	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_59	11.6065	-3.1833	30.09. - 03.10.2010	S. Porembski	Volta
Diospyros mespiliformis	Diospyros_68	11.6066	2.0206	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_69	11.6066	2.0206	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_16	11.6547	-4.4635	09.06. - 02.07.2009	I. Kirchmair	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Diospyros mespiliformis	Diospyros_15	11.6662	-4.4610	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_62	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_64	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_65	11.6807	2.2284	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_66	11.6807	2.2284	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_67	11.6807	2.2284	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_60	11.6812	1.9940	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_61	11.6812	1.9940	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_72	11.7918	1.7502	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_74	11.7918	1.7502	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Diospyros mespiliformis	Diospyros_78	12.3216	1.6633	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_79	12.3216	1.6633	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_52	12.4425	-1.3536	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_93	12.4428	-1.3531	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_94	12.4428	-1.3531	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Diospyros mespiliformis	Diospyros_25	12.5041	-3.5530	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_23	12.5055	-3.5538	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_24	12.5056	-3.5539	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_33	12.5167	-3.2535	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_32	12.5168	-3.2547	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_34	12.5170	-3.2531	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_31	12.6437	-3.4639	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_29	12.6442	-3.4644	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_30	12.6442	-3.4644	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_51	12.7527	-1.1533	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_26	12.7537	-3.4369	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_27	12.7547	-3.4376	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_28	12.7547	-3.4376	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_50	13.2013	-1.1394	09.06. - 02.07.2009	I. Kirchmair	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Diospyros mespiliformis	Diospyros_49	13.2015	-1.1397	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_48	13.2018	-1.1398	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_37	13.6379	-2.6624	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_36	13.6383	-2.6622	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_35	13.6385	-2.6622	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_40	13.6812	-2.2132	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_38	13.6815	-2.2134	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_39	13.6815	-2.2134	09.06. - 02.07.2009	I. Kirchmair	Volta
Diospyros mespiliformis	Diospyros_46	13.8982	-1.6537	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_47	13.8982	-1.6538	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_45	13.8983	-1.6537	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_41	14.0992	-1.7179	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_42	14.0992	-1.7179	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_43	14.1001	-1.7176	09.06. - 02.07.2009	I. Kirchmair	Niger
Diospyros mespiliformis	Diospyros_44	14.3263	-1.4956	09.06. - 02.07.2009	I. Kirchmair	Niger
Paullinia pinnata	Paullinia_06	9.7030	-4.5864	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_05	9.9305	-4.6079	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_04	9.9316	-4.6084	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_03	9.9319	-4.6086	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_09	10.5994	-5.3135	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_08	10.5997	-5.3131	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_07	10.6015	-5.3113	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_31	10.6508	-4.8173	30.09. - 03.10.2010	S. Porembski	West Coast
Paullinia pinnata	Paullinia_32	10.6508	-4.8173	30.09. - 03.10.2010	S. Porembski	West Coast
Paullinia pinnata	Paullinia_01	10.7217	-4.8216	09.06. - 02.07.2009	I. Kirchmair	West Coast

Species	**Sample ID**	**Lat**	**Long**	**Date**	**Collector**	**River basin**
Paullinia pinnata	Paullinia_02	10.7226	-4.8220	09.06. - 02.07.2009	I. Kirchmair	West Coast
Paullinia pinnata	Paullinia_44	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_45	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_46	11.0967	0.5883	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_27	11.0972	-0.7074	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_25	11.0972	-0.7078	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_26	11.0973	-0.7076	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_12	11.1886	-4.4433	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_10	11.1895	-4.4416	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_11	11.1896	-4.4418	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_47	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_48	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_49	11.2072	1.3006	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_41	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Paullinia pinnata	Paullinia_42	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_43	11.2844	1.0157	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_22	11.4380	-1.1786	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_23	11.4381	-1.1787	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_24	11.4381	-1.1789	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_73	11.4386	-1.1774	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_74	11.4386	-1.1774	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_75	11.4386	-1.1774	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_68	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_69	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_70	11.5398	2.0556	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_13	11.5480	-4.1102	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_14	11.5483	-4.1104	09.06. - 02.07.2009	I. Kirchmair	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Paullinia pinnata	Paullinia_15	11.5483	-4.1104	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_38	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_39	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_40	11.5731	1.4519	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_16	11.5991	-4.1300	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_17	11.5991	-4.1301	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_18	11.5992	-4.1300	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_33	11.6065	-3.1833	30.09. - 03.10.2010	S. Porembski	Volta
Paullinia pinnata	Paullinia_34	11.6065	-3.1833	30.09. - 03.10.2010	S. Porembski	Volta
Paullinia pinnata	Paullinia_65	11.6066	2.0206	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_66	11.6066	2.0206	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_67	11.6066	2.0206	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_35	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta

Species	Sample ID	Lat	Long	Date	Collector	River basin
Paullinia pinnata	Paullinia_36	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_37	11.6722	2.1235	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_63	11.6812	1.9940	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_64	11.6812	1.9940	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Volta
Paullinia pinnata	Paullinia_71	12.3216	1.6633	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Niger
Paullinia pinnata	Paullinia_72	12.3216	1.6633	25.10. - 03.11.2008	E. Mbayngone, M. Schmidt, T. Janßen, C. Siniaré, Y. Yameogo & M. Greve	Niger
Paullinia pinnata	Paullinia_21	12.5042	-3.5531	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_20	12.5046	-3.5535	09.06. - 02.07.2009	I. Kirchmair	Volta
Paullinia pinnata	Paullinia_19	12.5046	-3.5537	09.06. - 02.07.2009	I. Kirchmair	Volta
Pterocarpus santalinoides	Pterocarpus_04	9.7030	-4.5864	09.06. - 02.07.2009	I. Kirchmair	West Coast
Pterocarpus santalinoides	Pterocarpus_05	9.7034	-4.5864	09.06. - 02.07.2009	I. Kirchmair	West Coast
Pterocarpus santalinoides	Pterocarpus_15	10.6508	-4.8173	30.09. - 03.10.2010	S. Porembski	West Coast
Pterocarpus santalinoides	Pterocarpus_14	10.6886	-4.8074	30.09. - 03.10.2010	S. Porembski	West Coast
Pterocarpus santalinoides	Pterocarpus_13	10.7171	-4.8173	30.09. - 03.10.2010	S. Porembski	West Coast
Pterocarpus santalinoides	Pterocarpus_12	10.7181	-4.8206	30.09. - 03.10.2010	S. Porembski	West Coast
Pterocarpus santalinoides	Pterocarpus_01	10.7217	-4.8216	09.06. - 02.07.2009	I. Kirchmair	West Coast

Species	Sample ID	Lat	Long	Date	Collector	River basin
Pterocarpus santalinoides	Pterocarpus_02	10.7217	-4.8216	09.06. - 02.07.2009	I. Kirchmair	West Coast
Pterocarpus santalinoides	Pterocarpus_11	10.8196	-4.8202	30.09. - 03.10.2010	S. Porembski	Volta
Pterocarpus santalinoides	Pterocarpus_06	11.5983	-4.1295	09.06. - 02.07.2009	I. Kirchmair	Volta
Pterocarpus santalinoides	Pterocarpus_09	12.5048	-3.5538	09.06. - 02.07.2009	I. Kirchmair	Volta
Pterocarpus santalinoides	Pterocarpus_08	12.5051	-3.5539	09.06. - 02.07.2009	I. Kirchmair	Volta
Pterocarpus santalinoides	Pterocarpus_10	12.7532	-3.4375	09.06. - 02.07.2009	I. Kirchmair	Volta

9.2 AFLP Primers

This supplementary material shows all primer combination tested and the primers finally used for the four study species.

Tested primer combinations

Primers ending on: -A (MseI + HindIII)

	HindIII – ACA	HindIII – AAC	HindIII – AGC
MseI – ACG	Comb. 1	Comb. 2	Comb. 3
MseI – AGC	Comb. 4	Comb. 5	Comb. 6
MseI – ACC	Comb. 7	Comb. 8	Comb. 9
MseI – ACA	Comb. 10	Comb. 11	Comb. 12
MseI – ATG	Comb. 13	Comb. 14	Comb. 15
MseI – ATC	Comb. 16	Comb. 17	Comb. 18
MseI – AGG	Comb. 19	Comb. 20	Comb. 21
MseI – AGA	Comb. 22	Comb. 23	Comb. 24

Primers ending on: -C (MseI) and -A (HindIII)

	HindIII – ACA	HindIII – AAC	HindIII – AGC
MseI – CAA	Comb. 25	Comb. 26	Comb. 27
MseI – CAC	Comb. 28	Comb. 29	Comb. 30
MseI – CGA	Comb. 31	Comb. 32	Comb. 33
MseI – CAG	Comb. 34	Comb. 35	Comb. 36
MseI – CTG	Comb. 37	Comb. 38	Comb. 39
MseI – CTA	Comb. 40	Comb. 41	Comb. 42
MseI – CTC	Comb. 43	Comb. 44	Comb. 45
MseI – CAT	Comb. 46	Comb. 47	Comb. 48
MseI – CTT	Comb. 49	Comb. 50	Comb. 51

Used primer combinations

Species	primer combinations
Anogeissus leiocarpa	1, 2, 3, 4, 5, 6, 7, 8, 9
Diospyros mespiliformis	7, 8, 10, 11, 12, 17, 22, 24
Paullinia pinnata	17, 18, 20, 21, 28, 43, 44, 45, 49
Pterocarpus santalinoides	25, 26, 34, 35, 43, 44, 46, 47

9.3 DNA Extraction and AFLP Protocol

DNA extraction protocol (QIAGEN DNeasy Plant Kit)

- disrupt samples either with a mix mill (samples in silica gel) or a mortar and pestle (samples in CTAB Buffer)
- add 400 µl Buffer AP1, 10 µl Proteinase K (20mg/ml) and 30 µl 2-Mercaptoethanol
- mix and incubate for 24 hours at 42°C, invert tubes several times during incubation
- Preheat a water bath or heating block to 65°C to incubate Buffer AE (will be used later)
- add 130 µl Buffer AP2 to every sample, mix and incubate for 5 min on ice
- centrifuge lysate for 5 min at 14,000 rpm
- pipet lysate into a QIAshredder Mini Spin Column placed in a 2 ml collection tube, centrifuge for 2 min at 14,000 rpm
- transfer the flow-through into a new micro centrifuge tube without disturbing the pellet if present
- discard tube, add 1.5 volumes of Buffer AP3/E and mix by pipetting
- transfer 650 µl of the mixture into a DNeasy Mini Spin Column placed in a 2 ml collection tube, centrifuge for 1 min at 8000 rpm
- discard flow-through, repeat this step with the remaining sample
- place spin column into a new 2 ml collection tube, add 500 µl Buffer AW, centrifuge for 1 min at 8000 rpm, discard the flow-through
- add another 500 µl Buffer AW, centrifuge for 2 min at 14,000 rpm
- transfer spin column to a new 1.5 ml micro centrifuge tube, add 100 µl Buffer AE for elution
- incubate for 5 min at room temperature (15–25°C), centrifuge for 1 min at 8000 rpm
- add another 500 µl Buffer AW, centrifuge for 2 min at 14,000 rpm

AFLP protocol

1. Adapter preparation
   - HindIII-adapter 2.5 pmol/µl and MseI-adapter 25pmol/µl
   - transfer needed adapter amounts to PCR-tubes, put the tubes into the thermocycler (5’ at 95°C, 10’ at roomtemperature); adapters always need to be denatured after freezing!
   - store at –20°C

2. Restriction and Ligation
    - first provide the DNA to the PCR tubes
    - produce mastermix (always keep it on ice) and add 11,6 µl mastermix to every sample
    - mastermix: 10 x T_4-ligase-buffer with ATP, NaCl [0,5 M], BSA [1 µg/µl], MseI adapter pair [25 pmol/µl], HindIII adapter pair [2,5 pmol/µl], T_4-DNA-ligase [5 U/µl], HindIII [10 U/µl], MseI [10 U/µl], DNA [30 ng/µl]
    - spin samples down and incubate in thermocycler (12 h at 37°C, 20' at 80°C, forever at 4°C)
    - dilute every sample 1:10 with H_2O (autoclaved Millipore water), keep the samples always on ice (MseI is not inactivated by heating to 80°C)
    - mix 90 µl H_2O with 10 µl of your digest
    - spin dilutions down
    - store at –20°C
    - for the pre-selective PCR you need 2 µl diluted restriction/ligation product

3. Pre-selective PCR
    - for the pre-selective PCR you need 2 µl diluted restriction/ligation product
    - pre-selective primers (one selective base): HindIII–A, MseI–A, MseI–C
    - provide diluted products from step 'Restriction and Ligation' to PCR tubes
    - produce mastermix (always keep it on ice), add 8 µl mastermix to every sample
    - mastermix: 10 x PCR Puffer (Peqlab blue), $MgCl_2$ [25 mM], MseI–primer [10 µM], Hind III–primer [10 µM], dNTP's [2 mM], Taq Polymerase (Peqlab) [5 U/µl], H_2O
    - spin your samples down and incubate in thermocycler (1x 2' at 94°C; 30x 20'' at 94°C, 30'' at 56°C, 2' at 72°C; 1x 2' at 72°C, 30' at 60°C, forever at 4°C
    - dilute every sample 1:20 with H_2O (autoclaved Millipore water)
    - mix 95 µl H_2O with 5 µl pre-selective PCR product
    - vortex and spin down your dilutions
    - store at –20°C
    - for the selective PCR you need 2,5µl diluted pre-selective PCR product

4. Selective PCR
    - provide the diluted pre-selective PCR products to PCR tubes
    - produce mastermix (always keep it on ice), add 7,5 µl mastermix to every sample
    - mastermix: 10 x PCR Puffer (Peqlab blue), $MgCl_2$ [25 mM], MseI–primer [5 µM], Hind III–primer [1 µM], dNTP's [2 mM], Taq Polymerase (Peqlab) [5 U/µl], 1:20 diluted pre-selective PCR product, H_2O
    - spin your samples down and incubate samples in thermocycler (1x 2'' at 94°C; 15x 20'' at 94°C, 30'' at 66°C, decrease by 0,7 °C every cycle, 2' at 72°C; 20x 20'' at 94°C, 30'' at 56°C, 2' at 72°C, 1x 30' at 60°C, forever at 4°C)

9.4 Classification of Gallery Forest Species of Burkina Faso

This supplementary material shows life-form, habitat and use classification of species occurring in GFs in Burkina Faso. The nomenclature follows African Plants Database (version 3.4.0, 2012).

Species	Family	Life-form	Habitat	Use
Abelmoschus moschatus	Malvaceae	therophyte	GF, ruderal	medicine
Abildgaardia ovata	Cyperaceae	therophyte	GF, savanna, forest	-
Abrus canescens	Fabaceae	liana	GF, savanna, forest	medicine
Abrus melanospermus	Fabaceae	liana	GF, forest	medicine
Abrus precatorius	Fabaceae	liana	GF, savanna, forest	medicine, nutrition, firewood, ornamental
Acacia ataxacantha	Fabaceae	liana	GF, savanna, forest	medicine, fodder, firewood, construction, tool craft, religion/art
Acalypha ceraceopunctata	Euphorbiaceae	therophyte	GF, forest	-
Acridocarpus chevalieri	Malpighiaceae	phanerophyte	GF, forest	medicine, religion/art
Adiantum philippense	Pteridaceae	hemicryptophyte	GF	-
Afzelia africana	Fabaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art
Agelanthus dodoneifolius	Loranthaceae	epiphyte	GF, savanna, forest	medicine, fodder, veterinary
Albizia dinklagei	Fabaceae	phanerophyte	GF, forest	-
Alchornea cordifolia	Euphorbiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, tool craft

Species	Family	Life-form	Habitat	Use
Ampelocissus leonensis	Vitaceae	liana	GF, savanna, forest	medicine
Ampelocissus multistriata	Vitaceae	liana	GF, savanna, forest	medicine
Anchomanes difformis	Araceae	geophyte	GF, forest	medicine
Ancylobotrys amoena	Apocynaceae	liana	GF, savanna, forest	medicine, nutrition
Andropogon fastigiatus	Poaceae	therophyte	GF, savanna, forest, ruderal	fodder
Andropogon pseudapricus	Poaceae	therophyte	GF, savanna, forest, ruderal	fodder, construction
Andropogon tectorum	Poaceae	hemicryptophyte	GF	fodder, construction
Anogeissus leiocarpa	Combretaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art
Anthocleista djalonensis	Gentianaceae	phanerophyte	GF, forest	medicine
Anthocleista procera	Gentianaceae	phanerophyte	GF, forest	medicine
Antidesma rufescens	Euphorbiaceae	phanerophyte	GF, savanna, forest	-
Antidesma venosum	Euphorbiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, construction, tool craft
Ascolepis capensis	Cyperaceae	hemicryptophyte	GF, forest	-
Asparagus schroederi	Asparagaceae	liana	GF, savanna, forest, ruderal	-
Asystasia gangetica	Acanthaceae	therophyte	GF, forest	medicine, nutrition

Species	Family	Life-form	Habitat	Use
Berlinia grandiflora	Fabaceae	phanerophyte	GF, forest	medicine, construction, ornamental, religion/art
Bidens engleri	Asteraceae	therophyte	GF, forest	medicine
Brachiaria brizantha	Poaceae	hemicryptophyte	GF	-
Breonadia salicina	Rubiaceae	phanerophyte	GF, forest	medicine, construction, tool craft
Bridelia micrantha	Phyllanthaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrtion, firewood, construction, tool craft, veterinary
Bulbostylis pilosa	Cyperaceae	hemicryptophyte	GF, savanna, forest, ruderal	-
Byrsanthus brownii	Salicaceae	phanerophyte	GF, forest	-
Campylospermum flavum	Ochnaceae	phanerophyte	GF, forest	-
Campylospermum squamosum	Ochnaceae	phanerophyte	GF, forest	-
Carapa procera	Meliaceae	phanerophyte	GF, forest	medicine, nutrition, construction, religion/art
Cassia podocarpa	Fabaceae	phanerophyte	GF, forest	medicine
Cassia sieberiana	Fabaceae	phanerophyte	GF, savanna, forest	medicine, fodder, firewood, construction, tool craft, veterinary
Cassipourea congoensis	Rhizophoraceae	phanerophyte	GF, forest	-
Cassytha filiformis	Lauraceae	phanerophyte	GF	medicine
Cayratia gracilis	Vitaceae	liana	GF, savanna, forest, ruderal	medicine
Ceiba pentandra	Malvaceae	phanerophyte	GF, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art
Celtis toka	Cannabaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, religion/art

Species	Family	Life-form	Habitat	Use
Ceropegia campanulata	Apocynaceae	liana	GF, forest	-
Chasmanthera dependens	Menispermaceae	liana	GF, savanna, forest	medicine
Chlorophytum lancifolium	Asparagaceae	hemicryptophyte	GF, forest	-
Chlorophytum orchidastrum	Asparagaceae	hemicryptophyte	GF, forest	-
Cissus aralioides	Vitaceae	liana	GF, savanna, forest	medicine, tool craft, ornamental
Cissus diffusiflora	Vitaceae	liana	GF, forest	medicine
Cissus doeringii	Vitaceae	phanerophyte	GF, savanna, forest, ruderal	-
Cissus palmatifida	Vitaceae	liana	GF, savanna, forest, ruderal	-
Cissus petiolata	Vitaceae	liana	GF, forest, ruderal	-
Cissus producta	Vitaceae	liana	GF, forest	-
Cola gigantea	Malvaceae	phanerophyte	GF, forest	medicine
Cola laurifolia	Malvaceae	phanerophyte	GF	construction
Combretum paniculatum	Combretaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, construction, tool craft, ornamental
Commelina lagosensis	Commelinaceae	chamaephyte	GF, forest	-
Costus lucanusianus	Costaceae	geophyte	GF, forest	-
Cremaspora triflora	Rubiaceae	phanerophyte	GF, savanna, forest	medicine
Crotalaria ochroleuca	Fabaceae	therophyte	GF, forest	fodder
Crotalaria pallida	Fabaceae	chamaephyte	GF, forest	medicine, nutrition
Cryptolepis sanguinolenta	Apocynaceae	phanerophyte	GF, forest	medicine, nutrition, tool craft

Species	Family	Life-form	Habitat	Use
Curculigo pilosa	Hypoxidaceae	geophyte	GF, savanna, forest	medicine
Cyathula achyranthoides	Amaranthaceae	therophyte	GF, forest	medicine
Cyathula prostrata	Amaranthaceae	therophyte	GF, forest	medicine
Cymbopogon caesius	Poaceae	hemicryptophyte	GF, savanna, forest, ruderal	medicine, nutrition, construction, religion/art
Cyperus difformis	Cyperaceae	therophyte	GF, savanna, forest, ruderal	-
Cyperus pustulatus	Cyperaceae	therophyte	GF, savanna, forest	-
Cyperus reduncus	Cyperaceae	therophyte	GF, savanna, forest	fodder
Cyphostemma crotalarioides	Vitaceae	geophyte	GF, savanna, forest	-
Cyphostemma vogelii	Vitaceae	phanerophyte	GF, savanna, forest, ruderal	medicine
Desmodium adscendens	Fabaceae	chamaephyte	GF, forest	medicine, fodder
Desmodium gangeticum	Fabaceae	therophyte	GF, savanna, forest	medicine
Desmodium ospriostreblum	Fabaceae	therophyte	GF, forest, ruderal	-
Desmodium salicifolium	Fabaceae	phanerophyte	GF, forest	medicine
Desmodium velutinum	Fabaceae	chamaephyte	GF, savanna, forest	medicine, fodder
Detarium senegalense	Fabaceae	phanerophyte	GF, forest	medicine, nutrition, fodder, construction, tool craft, ornamental
Dialium guineense	Fabaceae	phanerophyte	GF, forest	medicine, nutrition, fodder, firewood, construction, tool craft

Species	Family	Life-form	Habitat	Use
Dioscorea abyssinica	Dioscoreaceae	liana	GF, savanna, forest, ruderal	nutrition
Dioscorea dumetorum	Dioscoreaceae	liana	GF, savanna, forest, ruderal	medicine, nutrition
Dioscorea hirtiflora	Dioscoreaceae	liana	GF, forest, ruderal, inselbergs	-
Dioscorea sagittifolia	Dioscoreaceae	liana	GF, savanna, forest	-
Diospyros ferrea	Ebenaceae	phanerophyte	GF, forest	firewood
Diospyros mespiliformis	Ebenaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art, veterinary
Dissomeria crenata	Salicaceae	phanerophyte	GF, savanna, forest	-
Dissotis thollonii	Melastomataceae	chamaephyte	GF, savanna, forest	medicine, ornamental
Drypetes floribunda	Euphorbiaceae	phanerophyte	GF, forest	-
Dyschoriste nagchana	Acanthaceae	therophyte	GF, savanna, forest, ruderal	medicine, fodder
Eclipta prostrata	Asteraceae	therophyte	GF, forest	medicine, nutrition
Ekebergia capensis	Meliaceae	phanerophyte	GF, savanna, forest	medicine, religion/art
Elaeis guineensis	Arecaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, construction
Elephantopus mollis	Asteraceae	phanerophyte	GF, savanna, forest, ruderal	-
Elytraria marginata	Acanthaceae	chamaephyte	GF, forest	-
Englerastrum schweinfurthii	Lamiaceae	therophyte	GF, forest	-
Eriocoelum kerstingii	Sapindaceae	phanerophyte	GF, savanna, forest	-

Species	Family	Life-form	Habitat	Use
Eriosema macrostipulum	Fabaceae	hemicryptophyte	GF, savanna, forest	-
Eriosema psoraloides	Fabaceae	chamaephyte	GF, savanna, forest	medicine, veterinary
Erythrina sigmoidea	Fabaceae	phanerophyte	GF, savanna, forest	-
Erythrophleum suaveolens	Fabaceae	phanerophyte	GF, savanna, forest	medicine, firewood, construction, toolcraft
Ethulia conyzoides	Asteraceae	therophyte	GF, savanna, forest	-
Eulophia guineensis	Orchidaceae	hemicryptophyte	GF, forest	ornamental
Euphorbia thymifolia	Euphorbiaceae	chamaephyte	GF, savanna, forest, ruderal	medicine
Euphorbia unispina	Euphorbiaceae	phanerophyte	GF, savanna, forest	medicine, ornamental
Fadogia erythrophloea	Rubiaceae	phanerophyte	GF, savanna, forest	medicine
Ficus abutilifolia	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, religion/art
Ficus asperifolia	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, construction, tool craft
Ficus capreifolia	Moraceae	phanerophyte	GF, forest	medicine, nutrition, contruction, tool craft
Ficus lutea	Moraceae	phanerophyte	GF, savanna, forest	-
Ficus natalensis	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, construction, religion/art
Ficus ovata	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, religion/art
Ficus polita	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, religion/art

Species	Family	Life-form	Habitat	Use
Ficus scott-elliotii	Moraceae	phanerophyte	GF, forest	-
Ficus thonningii	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft
Ficus trichopoda	Moraceae	phanerophyte	GF, forest	medicine, nutrition, firewood, contruction, religion/art
Ficus vallis-choudae	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood
Ficus vogeliana	Moraceae	phanerophyte	GF, savanna, forest	medicine, nutrition, tool craft, religion/art
Flacourtia indica	Salicaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, construction
Flemingia faginea	Fabaceae	phanerophyte	GF, savanna, forest	medicine, veterinary
Garcinia livingstonei	Clusiaceae	phanerophyte	GF, forest	nutrition
Garcinia ovalifolia	Clusiaceae	phanerophyte	GF, forest	-
Gardenia imperialis	Rubiaceae	phanerophyte	GF, forest	medicine
Glinus lotoides	Molluginaceae	therophyte	GF, savanna, forest	medicine
Gnidia kraussiana	Thymelaeaceae	chamaephyte	GF, savanna	medicine
Guibourtia copallifera	Fabaceae	phanerophyte	GF, forest	medicine, firewood, construction, toolcraft
Hexalobus monopetalus	Annonaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft
Holarrhena floribunda	Apocynaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, ornamental, religion/art, veterinary
Hoslundia opposita	Lamiaceae	chamaephyte	GF, savanna, forest, ruderal	medicine, nutrition
Hydrolea palustris	Hydroleaceae	therophyte	GF, forest	-
Hyparrhenia glabriuscula	Poaceae	hemicryptophyte	GF, savanna, forest, inselbergs	fodder

Species	Family	Life-form	Habitat	Use
Hyparrhenia subplumosa	Poaceae	hemicryptophyte	GF, savanna, forest	fodder
Hypoestes aristata	Acanthaceae	phanerophyte	GF, savanna, forest, ruderal	tool craft
Hypoestes cancellata	Acanthaceae	phanerophyte	GF, forest	-
Hypoestes forskaolii	Acanthaceae	chamaephyte	GF, forest	-
Hyptis lanceolata	Lamiaceae	phanerophyte	GF, savanna, forest	medicine
Indigofera macrophylla	Fabaceae	liana	GF, savanna, forest	medicine
Indigofera nigritana	Fabaceae	therophyte	GF, forest	medicine
Indigofera paniculata	Fabaceae	therophyte	GF, savanna, forest	medicine, fodder
Indigofera pilosa	Fabaceae	therophyte	GF, savanna, forest, inselbergs	fodder
Indigofera spicata	Fabaceae	chamaephyte	GF, savanna, forest, ruderal	fodder
Indigofera suffruticosa	Fabaceae	phanerophyte	GF, forest	medicine, tool craft
Ipomoea chrysochaetia	Convolvulaceae	liana	GF, forest	religion/art
Ipomoea involucrata	Convolvulaceae	liana	GF, savanna, forest, ruderal	medicine
Ipomoea mauritiana	Convolvulaceae	liana	GF, forest, ruderal	medicine
Ipomoea turbinata	Convolvulaceae	liana	GF, forest	ornamental
Ischaemum amethystinum	Poaceae	hemicryptophyte	GF, savanna, forest	nutrition
Ixora brachypoda	Rubiaceae	phanerophyte	GF, forest	-

Species	Family	Life-form	Habitat	Use
Jasminum dichotomum	Oleaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, ornamental
Jasminum obtusifolium	Oleaceae	liana	GF, savanna, forest, ruderal	veterinary
Justicia insularis	Acanthaceae	chamaephyte	GF, savanna, forest, ruderal	-
Justicia tenella	Acanthaceae	chamaephyte	GF, forest	-
Keetia cornelia	Rubiaceae	liana	GF, forest	tool craft
Keetia mannii	Rubiaceae	liana	GF, savanna, forest	-
Keetia venosa	Rubiaceae	phanerophyte	GF, forest	medicine, nutrition
Khaya grandifoliola	Meliaceae	phanerophyte	GF, forest	ornamental
Khaya senegalensis	Meliaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, ornamental, religion/art, veterinary
Kigelia africana	Bignoniaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft
Kinghamia macrocephala	Asteraceae	phanerophyte	GF, savanna, forest	-
Kinghamia nigritana	Asteraceae	phanerophyte	GF, savanna, forest	-
Lagenaria breviflora	Cucurbitaceae	phanerophyte	GF, forest	ornamental
Landolphia dulcis	Apocynaceae	phanerophyte	GF, savanna, forest	medicine, nutrition
Landolphia hirsuta	Apocynaceae	liana	GF, savanna, forest	nutrition
Landolphia owariensis	Apocynaceae	liana	GF, savanna, forest	-
Lannea barteri	Anacardiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft
Lepidagathis alopecuroides	Acanthaceae	chamaephyte	GF, forest	-

Species	Family	Life-form	Habitat	Use
Leucas martinicensis	Lamiaceae	therophyte	GF, forest	medicine
Lipocarpha chinensis	Cyperaceae	therophyte	GF, forest	-
Loeseneriella africana	Celastraceae	liana	GF, forest	medicine, construction, tool craft
Lonchocarpus sericeus	Fabaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, construction, tool craft, ornamental, religion/art
Luffa acutangula	Cucurbitaceae	liana	GF, forest	-
Macrosphyra longistyla	Rubiaceae	phanerophyte	GF, forest	medicine, nutrition
Maerua pseudopetalosa	Capparaceae	chamaephyte	GF, savanna, forest	-
Manilkara multinervis	Sapotaceae	phanerophyte	GF, savanna	medicine, firewood, construction
Manilkara obovata	Sapotaceae	phanerophyte	GF, savanna, forest	medicine, firewood, construction
Margaritaria discoidea	Phyllanthaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, fodder, firewood
Markhamia tomentosa	Bignoniaceae	phanerophyte	GF, forest, ruderal	medicine, tool craft, ornamental, religion/art
Melastomastrum capitatum	Melastomataceae	phanerophyte	GF, forest	medicine, ornamental
Merremia hederacea	Convolvulaceae	liana	GF, forest	-
Merremia umbellata	Convolvulaceae	liana	GF, forest	medicine
Mikania chevalieri	Asteraceae	liana	GF, forest	medicine, fodder, tool craft
Mimusops kummel	Sapotaceae	phanerophyte	GF, savanna, forest	-

Species	Family	Life-form	Habitat	Use
Mitragyna inermis	Rubiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art, veterinary
Monanthotaxis parvifolia	Annonaceae	phanerophyte	GF, forest	-
Monechma depauperatum	Acanthaceae	chamaephyte	GF, savanna, ruderal	-
Monotes kerstingii	Dipterocarpaceae	phanerophyte	GF, savanna, forest	medicine
Morelia senegalensis	Rubiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, tool craft
Mussaenda elegans	Rubiaceae	phanerophyte	GF, savanna, forest	-
Myrianthus serratus	Moraceae	phanerophyte	GF, forest	-
Napoleonaea heudelotii	Lecythidaceae	phanerophyte	GF, forest	-
Nelsonia canescens	Acanthaceae	therophyte	GF, savanna, forest	medicine
Nelsonia smithii	Acanthaceae	hemicryptophyte	GF, forest	-
Neorautanenia mitis	Fabaceae	phanerophyte	GF, savanna, forest	medicine
Nephrolepis biserrata	Oleandraceae	epiphyte	GF, forest	-
Nervilia adolphi	Orchidaceae	geophyte	GF, savanna, forest	medicine
Nervilia bicarinata	Orchidaceae	geophyte	GF, savanna, forest	medicine
Ochna afzelii	Ochnaceae	phanerophyte	GF, savanna, forest	-
Ochna schweinfurthiana	Ochnaceae	phanerophyte	GF, savanna, forest	medicine, tool craft
Olax subscorpioidea	Olacaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, religion/art

Species	Family	Life-form	Habitat	Use
Omphalogonus calophyllus	Apocynaceae	phanerophyte	GF, forest	-
Oncoba spinosa	Salicaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, tool craft, ornamental
Opilia amentacea	Opiliaceae	liana	GF, savanna, forest, inselbergs	medicine, nutrition, religion/art
Oplismenus hirtellus	Poaceae	chamaephyte	GF, forest	-
Oxytenanthera abyssinica	Poaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, ornamental, religion/art
Parinari congensis	Chrysobalanaceae	phanerophyte	GF	-
Paullinia pinnata	Sapindaceae	liana	GF, savanna, forest, ruderal	medicine, nutrition, religion/art
Pavetta corymbosa	Rubiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition
Pericopsis laxiflora	Fabaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, fodder, firewood, construction, tool craft
Phaulopsis barteri	Acanthaceae	therophyte	GF, forest	-
Phaulopsis imbricata	Acanthaceae	therophyte	GF, forest	medicine
Philenoptera cyanescens	Fabaceae	liana	GF, savanna, forest	medicine, nutrition, tool craft
Phoenix reclinata	Arecaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, contruction, tool craft
Phyllanthus beillei	Phyllanthaceae	phanerophyte	GF, savanna, forest	medicine
Phyllanthus maderaspatensis	Phyllanthaceae	phanerophyte	GF, forest, ruderal	medicine
Phyllanthus muellerianus	Phyllanthaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, tool craft

Species	Family	Life-form	Habitat	Use
Phyllanthus pentandrus	Phyllanthaceae	phanerophyte	GF, forest, ruderal	medicine
Phyllanthus reticulatus	Phyllanthaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, construction, tool craft, religion/art
Phyllanthus sublanatus	Phyllanthaceae	therophyte	GF, savanna, forest, ruderal	-
Phyllanthus welwitschianus	Phyllanthaceae	phanerophyte	GF, savanna, forest	-
Platostoma africanum	Lamiaceae	therophyte	GF, savanna, forest	-
Plectranthus monostachyus	Lamiaceae	therophyte	GF, savanna, forest, inselbergs	-
Pouchetia africana	Rubiaceae	phanerophyte	GF, forest	medicine
Pouteria alnifolia	Sapotaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, construction, tool craft, religion/art
Premna lucens	Lamiaceae	phanerophyte	GF, forest	-
Pseudarthria fagifolia	Fabaceae	phanerophyte	GF, savanna	medicine
Pseudospondias microcarpa	Anacardiaceae	phanerophyte	GF, forest	-
Psophocarpus palustris	Fabaceae	phanerophyte	GF, forest	medicine, nutrition, fodder
Psychotria psychotrioides	Rubiaceae	phanerophyte	GF, forest	medicine
Psychotria vogeliana	Rubiaceae	phanerophyte	GF, forest	medicine
Psydrax horizontalis	Rubiaceae	phanerophyte	GF, forest	-

Species	Family	Life-form	Habitat	Use
Pterocarpus santalinoides	Fabaceae	phanerophyte	GF, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art
Pycreus flavescens	Cyperaceae	helophyte	GF, savanna, forest	-
Pycreus lanceolatus	Cyperaceae	helophyte	GF, forest, ruderal	-
Pycreus macrostachyos	Cyperaceae	therophyte	GF, forest	-
Raphia sudanica	Arecaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, construction, religion/art
Rauvolfia vomitoria	Apocynaceae	phanerophyte	GF, forest	medicine, religion/art
Rhaphiostylis beninensis	Icacinaceae	liana	GF, forest	-
Rhus longipes	Anacardiaceae	phanerophyte	GF, forest	nutrition, construction, tool craft
Rhynchosia pycnostachya	Fabaceae	phanerophyte	GF, forest	medicine
Rotala welwitschii	Lythraceae	hydrophyte	GF, forest, inselbergs, aquatic	-
Rothmannia longiflora	Rubiaceae	phanerophyte	GF, forest	-
Ruellia praetermissa	Acanthaceae	phanerophyte	GF, forest, ruderal	-
Rutidea parviflora	Rubiaceae	phanerophyte	GF, forest	medicine
Rytigynia senegalensis	Rubiaceae	phanerophyte	GF, savanna, forest	veterinary
Saba senegalensis	Apocynaceae	phanerophyte	GF, forest	medicine, nutrition, fodder, firewood, construction, tool craft
Salacia pallescens	Celastraceae	phanerophyte	GF, forest	-
Sarcocephalus latifolius	Rubiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, fodder, firewood, construction, tool craft, religion/art, veterinary

Species	Family	Life-form	Habitat	Use
Schizachyrium rupestre	Poaceae	hemicryptophyte	GF, forest	fodder
Scleria depressa	Cyperaceae	hemicryptophyte	GF, savanna, forest	medicine, religion/art
Scleria lagoensis	Cyperaceae	hemicryptophyte	GF, savanna, forest	-
Scleria racemosa	Cyperaceae	hemicryptophyte	GF, savanna, forest	medicine
Sebastiania chamaelea	Euphorbiaceae	chamaephyte	GF, savanna, forest, ruderal	medicine
Secamone afzelii	Apocynaceae	phanerophyte	GF, forest	medicine
Shirakiopsis elliptica	Euphorbiaceae	phanerophyte	GF, savanna, forest	medicine, tool craft
Sida rhombifolia	Malvaceae	hemicryptophyte	GF, savanna, forest, ruderal	medicine
Smeathmannia pubescens	Passifloraceae	phanerophyte	GF, forest	-
Sorindeia juglandifolia	Anacardiaceae	phanerophyte	GF, forest	medicine
Spondianthus preussii	Euphorbiaceae	phanerophyte	GF, forest	-
Stereospermum kunthianum	Bignoniaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, firewood, construction, tool craft, religion/art
Strophanthus sarmentosus	Apocynaceae	phanerophyte	GF, savanna, forest	medicine, construction, tool craft
Strychnos congolana	Loganiaceae	phanerophyte	GF, forest	-
Strychnos cuminodora	Loganiaceae	phanerophyte	GF, forest	-
Strychnos innocua	Loganiaceae	phanerophyte	GF, savanna, forest	medicine, nutrition
Strychnos usambarensis	Loganiaceae	phanerophyte	GF, forest	-

Species	Family	Life-form	Habitat	Use
Synsepalum brevipes	Sapotaceae	phanerophyte	GF, forest	medicine, nutrition
Synsepalum pobeguinianum	Sapotaceae	phanerophyte	GF, savanna, forest	nutrition, construction
Syzygium guineense	Myrtaceae	phanerophyte	GF, savanna	medicine, nutrition, firewood, construction, tool craft, religion/art
Tacazzea apiculata	Apocynaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, veterinary
Tapinanthus globiferus	Loranthaceae	epiphyte	GF, savanna, forest	medicine
Tarenna pavettoides	Rubiaceae	phanerophyte	GF, forest	-
Tarenna thomasii	Rubiaceae	phanerophyte	GF, forest	-
Terminalia schimperiana	Combretaceae	phanerophyte	GF, savanna, forest	medicine, firewood, construction, tool craft, religion/art
Thelepogon elegans	Poaceae	therophyte	GF, savanna, forest, ruderal	fodder
Thelypteris dentata	Thelypteridaceae	hemicryptophyte	GF	-
Trachypogon spicatus	Poaceae	hemicryptophyte	GF, savanna, forest	-
Tragia vogelii	Euphorbiaceae	phanerophyte	GF, savanna, forest, ruderal	-
Trema orientalis	Cannabaceae	phanerophyte	GF, savanna, forest, ruderal	medicine
Tricalysia okelensis	Rubiaceae	phanerophyte	GF, savanna, forest	medicine, firewood
Triclisia subcordata	Menispermaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, construction
Tristachya superba	Poaceae	geophyte	GF, savanna, forest, ruderal	fodder
Triumfetta pentandra	Malvaceae	therophyte	GF, forest	-
Triumfetta rhomboidea	Malvaceae	therophyte	GF, savanna, forest	medicine
Triumfetta setulosa	Malvaceae	chamaephyte	GF, savanna, forest, ruderal	-

Species	Family	Life-form	Habitat	Use
Uapaca heudelotii	Phyllanthaceae	phanerophyte	GF, forest	religion/art
Uapaca togoensis	Phyllanthaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, religion/art, veterinary
Uncaria africana	Rubiaceae	liana	GF, forest	-
Uncaria talbotii	Rubiaceae	phanerophyte	GF, forest	-
Uraria picta	Fabaceae	therophyte	GF, savanna, forest	medicine, religion/art
Urelytrum muricatum	Poaceae	hemicryptophyte	GF, savanna, forest	fodder
Uvaria chamae	Annonaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, firewood, contruction, religion/art
Vernonia colorata	Asteraceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition
Vigna adenantha	Fabaceae	phanerophyte	GF, forest	-
Vigna gracilis	Fabaceae	phanerophyte	GF, savanna, forest	nutrition
Vigna racemosa	Fabaceae	therophyte	GF, savanna, forest, ruderal	-
Vigna venulosa	Fabaceae	phanerophyte	GF	medicine, nutrition, fodder, firewood, construction, tool craft
Vitex chrysocarpa	Lamiaceae	phanerophyte	GF, forest	-
Vitex doniana	Lamiaceae	phanerophyte	GF, savanna	medicine
Voacanga africana	Apocynaceae	phanerophyte	GF, forest	-
Voacanga thouarsii	Apocynaceae	phanerophyte	GF, savanna, forest	-
Waltheria lanceolata	Malvaceae	phanerophyte	GF, savanna, forest	medicine
Warneckea fascicularis	Melastomataceae	phanerophyte	GF, savanna, forest	-
Xylopia acutiflora	Annonaceae	phanerophyte	GF, forest	medicine, nutrition, construction
Xylopia aethiopica	Annonaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, construction
Xylopia longipetala	Annonaceae	phanerophyte	GF, forest	-

Species	Family	Life-form	Habitat	Use
Zanthoxylum zanthoxyloides	Rutaceae	phanerophyte	GF, savanna, forest	medicine, nutrition, firewood, contruction, religion/art
Zehneria capillacea	Cucurbitaceae	liana	GF, forest	-
Ziziphus mucronata	Rhamnaceae	phanerophyte	GF, savanna, forest, ruderal	medicine, nutrition, fodder, firewood, construction, tool craft, veterinary

9.5 Classification of Samples to Genetic Populations

This supplementary material shows the classification of all individuals of the four study species to genetic populations according to the used programs *STRUCTURE*, *SplitsTree* and *BAPS*.

Species	Lat	Long	Structure	Splitstree	BAPS
Anogeissus leiocarpa	9.9135	-4.6261	2	2	2
Anogeissus leiocarpa	9.9135	-4.6256	2	2	2
Anogeissus leiocarpa	9.9137	-4.6252	2	2	2
Anogeissus leiocarpa	9.9301	-4.6190	2	2	2
Anogeissus leiocarpa	9.9315	-4.6087	1	2	3
Anogeissus leiocarpa	10.6171	-5.4170	1	2	3
Anogeissus leiocarpa	10.6196	-5.4244	1	1	3
Anogeissus leiocarpa	10.6478	-5.0352	1	1	3
Anogeissus leiocarpa	10.7083	-4.8144	1	3	3
Anogeissus leiocarpa	10.7220	-4.8207	1	1	3
Anogeissus leiocarpa	10.7221	-4.8207	3	3	1
Anogeissus leiocarpa	10.7221	-4.8207	3	3	1
Anogeissus leiocarpa	10.7225	-4.8211	1	3	3
Anogeissus leiocarpa	10.7233	-4.8220	1	1	3
Anogeissus leiocarpa	10.8196	-4.8202	1	1	3
Anogeissus leiocarpa	10.8233	-4.8223	1	3	3
Anogeissus leiocarpa	11.0967	0.5883	1	2	3
Anogeissus leiocarpa	11.0967	0.5883	3	2	1
Anogeissus leiocarpa	11.0967	0.5883	2	2	2
Anogeissus leiocarpa	11.0972	-0.7078	3	3	1
Anogeissus leiocarpa	11.0977	-0.7080	1	1	3
Anogeissus leiocarpa	11.0985	-0.7080	2	3	3
Anogeissus leiocarpa	11.1531	-4.1950	1	1	3
Anogeissus leiocarpa	11.1890	-4.4429	1	3	3
Anogeissus leiocarpa	11.1892	-4.4423	3	3	1
Anogeissus leiocarpa	11.2072	1.3006	2	2	2
Anogeissus leiocarpa	11.2791	-1.9281	1	1	3
Anogeissus leiocarpa	11.2791	-1.9277	3	3	1
Anogeissus leiocarpa	11.2793	-1.9283	1	3	3
Anogeissus leiocarpa	11.2844	1.0157	1	3	3
Anogeissus leiocarpa	11.2844	1.0157	3	2	1
Anogeissus leiocarpa	11.4386	-1.1774	2	2	2
Anogeissus leiocarpa	11.4389	-1.1803	1	1	3
Anogeissus leiocarpa	11.4398	-1.1797	1	3	3
Anogeissus leiocarpa	11.5398	2.0556	1	2	3
Anogeissus leiocarpa	11.5398	2.0556	2	3	2
Anogeissus leiocarpa	11.5473	-4.1092	2	3	2

Species	Lat	Long	Structure	Splitstree	BAPS
Anogeissus leiocarpa	11.5482	-4.1096	1	3	3
Anogeissus leiocarpa	11.5604	-4.1408	1	3	3
Anogeissus leiocarpa	11.5608	-4.1414	3	3	1
Anogeissus leiocarpa	11.5613	-4.1413	3	3	1
Anogeissus leiocarpa	11.5693	0.5317	1	2	3
Anogeissus leiocarpa	11.5693	0.5317	1	2	3
Anogeissus leiocarpa	11.5693	0.5317	1	2	3
Anogeissus leiocarpa	11.5731	1.4519	1	3	3
Anogeissus leiocarpa	11.5731	1.4519	1	3	3
Anogeissus leiocarpa	11.6066	2.0206	2	3	2
Anogeissus leiocarpa	11.6544	-4.4637	2	3	2
Anogeissus leiocarpa	11.6666	-4.4615	1	3	3
Anogeissus leiocarpa	11.6673	-4.4617	2	3	2
Anogeissus leiocarpa	11.6722	2.1235	1	1	3
Anogeissus leiocarpa	11.6722	2.1235	3	3	1
Anogeissus leiocarpa	11.6807	2.2284	1	2	3
Anogeissus leiocarpa	11.6807	2.2284	1	3	3
Anogeissus leiocarpa	11.6807	2.2284	1	3	3
Anogeissus leiocarpa	11.7789	-1.6019	1	1	3
Anogeissus leiocarpa	12.3216	1.6633	2	3	2
Anogeissus leiocarpa	12.4426	-1.3534	1	3	3
Anogeissus leiocarpa	12.4428	-1.3531	2	3	2
Anogeissus leiocarpa	12.4428	-1.3531	2	3	2
Anogeissus leiocarpa	12.5055	-3.5538	3	2	1
Anogeissus leiocarpa	12.5056	-3.5539	3	3	1
Anogeissus leiocarpa	12.5167	-3.2546	1	2	3
Anogeissus leiocarpa	12.5168	-3.2547	3	2	1
Anogeissus leiocarpa	12.5168	-3.2547	2	2	2
Anogeissus leiocarpa	12.5170	-3.2531	1	2	3
Anogeissus leiocarpa	12.6439	-3.4628	3	3	1
Anogeissus leiocarpa	12.6442	-3.4644	3	3	1
Anogeissus leiocarpa	12.6442	-3.4644	3	3	1
Anogeissus leiocarpa	12.7511	-3.4274	3	1	1
Anogeissus leiocarpa	12.7527	-1.1533	1	1	3
Anogeissus leiocarpa	12.7530	-1.1529	3	3	1
Anogeissus leiocarpa	12.7530	-1.1534	1	1	3
Anogeissus leiocarpa	13.2006	-1.1393	2	3	2
Anogeissus leiocarpa	13.8361	-2.0329	3	3	1
Anogeissus leiocarpa	13.8859	-1.9247	1	2	3
Anogeissus leiocarpa	13.8981	-1.6536	3	1	1
Anogeissus leiocarpa	13.8986	-1.6540	1	1	3
Anogeissus leiocarpa	13.8988	-1.6539	3	1	1
Anogeissus leiocarpa	14.2207	-1.5440	3	3	1
Anogeissus leiocarpa	14.2215	-1.5430	1	2	3
Anogeissus leiocarpa	14.2219	-1.5431	2	3	2
Anogeissus leiocarpa	14.2826	-1.4675	2	1	2

Species	Lat	Long	Structure	Splitstree	BAPS
Anogeissus leiocarpa	14.2828	-1.4668	2	1	2
Diospyros mespiliformis	9.8529	-4.6142	2	1	1
Diospyros mespiliformis	9.9146	-4.6253	1	2	1
Diospyros mespiliformis	9.9301	-4.6190	1	1	1
Diospyros mespiliformis	9.9306	-4.6186	1	2	1
Diospyros mespiliformis	9.9319	-4.6086	1	1	1
Diospyros mespiliformis	10.2624	-4.8858	1	2	1
Diospyros mespiliformis	10.2629	-4.8858	1	2	1
Diospyros mespiliformis	10.2634	-4.8860	1	1	1
Diospyros mespiliformis	10.6835	-5.1934	1	2	1
Diospyros mespiliformis	10.7218	-4.8204	1	2	1
Diospyros mespiliformis	10.7241	-4.8223	2	1	1
Diospyros mespiliformis	10.9286	-4.4928	3	4	2
Diospyros mespiliformis	11.0967	0.5883	3	3	2
Diospyros mespiliformis	11.0967	0.5883	3	4	2
Diospyros mespiliformis	11.1881	-4.4415	1	1	1
Diospyros mespiliformis	11.1898	-4.4420	1	2	1
Diospyros mespiliformis	11.1898	-4.4420	1	1	1
Diospyros mespiliformis	11.2072	1.3006	2	4	3
Diospyros mespiliformis	11.2072	1.3006	2	4	3
Diospyros mespiliformis	11.2072	1.3006	2	4	2
Diospyros mespiliformis	11.2844	1.0157	3	3	2
Diospyros mespiliformis	11.2844	1.0157	3	3	2
Diospyros mespiliformis	11.2844	1.0157	2	4	3
Diospyros mespiliformis	11.4381	-1.1787	2	1	3
Diospyros mespiliformis	11.4386	-1.1774	2	3	2
Diospyros mespiliformis	11.4386	-1.1774	3	3	2
Diospyros mespiliformis	11.4389	-1.1803	2	4	3
Diospyros mespiliformis	11.5398	2.0556	3	3	2
Diospyros mespiliformis	11.5398	2.0556	3	3	2
Diospyros mespiliformis	11.5486	-4.1098	1	2	1
Diospyros mespiliformis	11.5486	-4.1096	2	1	1
Diospyros mespiliformis	11.5486	-4.1096	2	1	1
Diospyros mespiliformis	11.5693	0.5317	2	4	3
Diospyros mespiliformis	11.5693	0.5317	3	3	2
Diospyros mespiliformis	11.5693	0.5317	3	3	2
Diospyros mespiliformis	11.5731	1.4519	3	3	2
Diospyros mespiliformis	11.5731	1.4519	3	3	2
Diospyros mespiliformis	11.5731	1.4519	3	4	2
Diospyros mespiliformis	11.5985	-4.1296	1	2	1
Diospyros mespiliformis	11.5986	-4.1296	2	1	3
Diospyros mespiliformis	11.5991	-4.1301	1	2	1
Diospyros mespiliformis	11.6065	-3.1833	2	4	2
Diospyros mespiliformis	11.6066	2.0206	3	4	2
Diospyros mespiliformis	11.6066	2.0206	3	4	2
Diospyros mespiliformis	11.6547	-4.4635	1	2	1

Species	**Lat**	**Long**	**Structure**	**Splitstree**	**BAPS**
Diospyros mespiliformis	11.6662	-4.4610	1	1	1
Diospyros mespiliformis	11.6722	2.1235	1	2	2
Diospyros mespiliformis	11.6722	2.1235	2	4	3
Diospyros mespiliformis	11.6807	2.2284	3	4	2
Diospyros mespiliformis	11.6807	2.2284	2	4	3
Diospyros mespiliformis	11.6807	2.2284	3	4	2
Diospyros mespiliformis	11.6812	1.9940	3	4	2
Diospyros mespiliformis	11.6812	1.9940	3	3	2
Diospyros mespiliformis	11.7918	1.7502	3	3	2
Diospyros mespiliformis	11.7918	1.7502	3	3	2
Diospyros mespiliformis	12.3216	1.6633	3	4	2
Diospyros mespiliformis	12.3216	1.6633	3	3	2
Diospyros mespiliformis	12.4425	-1.3536	2	4	3
Diospyros mespiliformis	12.4428	-1.3531	2	4	3
Diospyros mespiliformis	12.4428	-1.3531	3	3	2
Diospyros mespiliformis	12.5041	-3.5530	1	2	1
Diospyros mespiliformis	12.5055	-3.5538	1	2	1
Diospyros mespiliformis	12.5056	-3.5539	1	2	1
Diospyros mespiliformis	12.5167	-3.2535	1	2	1
Diospyros mespiliformis	12.5168	-3.2547	1	2	1
Diospyros mespiliformis	12.5170	-3.2531	1	2	1
Diospyros mespiliformis	12.6437	-3.4639	1	2	1
Diospyros mespiliformis	12.6442	-3.4644	2	1	1
Diospyros mespiliformis	12.6442	-3.4644	2	1	3
Diospyros mespiliformis	12.7527	-1.1533	2	1	1
Diospyros mespiliformis	12.7537	-3.4369	2	1	1
Diospyros mespiliformis	12.7547	-3.4376	1	2	1
Diospyros mespiliformis	12.7547	-3.4376	1	2	1
Diospyros mespiliformis	13.2013	-1.1394	1	1	1
Diospyros mespiliformis	13.2015	-1.1397	2	4	3
Diospyros mespiliformis	13.2018	-1.1398	2	1	3
Diospyros mespiliformis	13.6379	-2.6624	1	2	1
Diospyros mespiliformis	13.6383	-2.6622	1	1	1
Diospyros mespiliformis	13.6385	-2.6622	2	4	3
Diospyros mespiliformis	13.6812	-2.2132	1	2	1
Diospyros mespiliformis	13.6815	-2.2134	1	2	1
Diospyros mespiliformis	13.6815	-2.2134	1	2	1
Diospyros mespiliformis	13.8982	-1.6537	1	1	1
Diospyros mespiliformis	13.8982	-1.6538	1	2	1
Diospyros mespiliformis	13.8983	-1.6537	1	1	1
Diospyros mespiliformis	14.0992	-1.7179	1	2	1
Diospyros mespiliformis	14.0992	-1.7179	2	4	3
Diospyros mespiliformis	14.1001	-1.7176	1	2	1
Diospyros mespiliformis	14.3263	-1.4956	2	1	1
Paullinia pinnata	9.7030	-4.5864	1	1	3
Paullinia pinnata	9.9305	-4.6079	1	1	3

Species	**Lat**	**Long**	**Structure**	**Splitstree**	**BAPS**
Paullinia pinnata	9.9316	-4.6084	1	1	3
Paullinia pinnata	9.9319	-4.6086	1	1	3
Paullinia pinnata	10.5994	-5.3135	1	1	3
Paullinia pinnata	10.5997	-5.3131	1	1	3
Paullinia pinnata	10.6015	-5.3113	1	1	3
Paullinia pinnata	10.6508	-4.8173	1	2	2
Paullinia pinnata	10.6508	-4.8173	2	2	2
Paullinia pinnata	10.7217	-4.8216	1	1	3
Paullinia pinnata	10.7226	-4.8220	1	1	3
Paullinia pinnata	11.0967	0.5883	3	2	2
Paullinia pinnata	11.0967	0.5883	3	2	2
Paullinia pinnata	11.0967	0.5883	2	2	2
Paullinia pinnata	11.0972	-0.7074	2	2	1
Paullinia pinnata	11.0972	-0.7078	2	2	2
Paullinia pinnata	11.0973	-0.7076	1	1	3
Paullinia pinnata	11.1886	-4.4433	1	1	3
Paullinia pinnata	11.1895	-4.4416	2	2	1
Paullinia pinnata	11.1896	-4.4418	2	2	1
Paullinia pinnata	11.2072	1.3006	3	2	2
Paullinia pinnata	11.2072	1.3006	2	2	2
Paullinia pinnata	11.2072	1.3006	3	2	2
Paullinia pinnata	11.2844	1.0157	3	2	2
Paullinia pinnata	11.2844	1.0157	2	2	2
Paullinia pinnata	11.2844	1.0157	3	2	2
Paullinia pinnata	11.4380	-1.1786	1	1	3
Paullinia pinnata	11.4381	-1.1787	1	1	3
Paullinia pinnata	11.4381	-1.1789	1	1	3
Paullinia pinnata	11.4386	-1.1774	3	2	2
Paullinia pinnata	11.4386	-1.1774	3	2	2
Paullinia pinnata	11.4386	-1.1774	3	2	2
Paullinia pinnata	11.5398	2.0556	3	2	2
Paullinia pinnata	11.5398	2.0556	2	2	2
Paullinia pinnata	11.5398	2.0556	3	2	2
Paullinia pinnata	11.5480	-4.1102	1	1	3
Paullinia pinnata	11.5483	-4.1104	1	1	3
Paullinia pinnata	11.5483	-4.1104	1	1	3
Paullinia pinnata	11.5731	1.4519	3	2	2
Paullinia pinnata	11.5731	1.4519	3	2	2
Paullinia pinnata	11.5731	1.4519	3	2	2
Paullinia pinnata	11.5991	-4.1300	2	2	1
Paullinia pinnata	11.5991	-4.1301	1	2	2
Paullinia pinnata	11.5992	-4.1300	1	2	2
Paullinia pinnata	11.6065	-3.1833	2	2	2
Paullinia pinnata	11.6065	-3.1833	3	2	2
Paullinia pinnata	11.6066	2.0206	3	2	2
Paullinia pinnata	11.6066	2.0206	3	2	2

Species	Lat	Long	Structure	Splitstree	BAPS
Paullinia pinnata	11.6066	2.0206	3	2	2
Paullinia pinnata	11.6722	2.1235	3	2	2
Paullinia pinnata	11.6722	2.1235	3	2	2
Paullinia pinnata	11.6722	2.1235	3	2	2
Paullinia pinnata	11.6812	1.9940	3	2	2
Paullinia pinnata	11.6812	1.9940	3	2	2
Paullinia pinnata	12.3216	1.6633	3	2	2
Paullinia pinnata	12.3216	1.6633	3	2	2
Paullinia pinnata	12.5042	-3.5531	1	1	3
Paullinia pinnata	12.5046	-3.5535	1	1	3
Paullinia pinnata	12.5046	-3.5537	1	1	3
Pterocarpus santalinoides	9.7030	-4.5864	1	3	2
Pterocarpus santalinoides	9.7034	-4.5864	1	3	2
Pterocarpus santalinoides	10.6508	-4.8173	2	1	1
Pterocarpus santalinoides	10.6886	-4.8074	1	1	2
Pterocarpus santalinoides	10.7171	-4.8173	1	3	2
Pterocarpus santalinoides	10.7181	-4.8206	3	1	2
Pterocarpus santalinoides	10.7217	-4.8216	3	2	2
Pterocarpus santalinoides	10.7217	-4.8216	2	1	1
Pterocarpus santalinoides	10.8196	-4.8202	1	3	2
Pterocarpus santalinoides	11.5983	-4.1295	3	2	2
Pterocarpus santalinoides	12.5048	-3.5538	1	3	2
Pterocarpus santalinoides	12.5051	-3.5539	1	2	2
Pterocarpus santalinoides	12.7532	-3.4375	3	2	2

9.6 Species Distribution Modelling

This supplementary material shows the AUC values, the estimates of relative contributions of the environmental variables to the MaxEnt model (variable contributions), the 'equal training sensitivity and specificity threshold' and additional information. See the Zenodo repository (doi:10.5281/zenodo.376190).

9.7 Species-tree Diffusion Models

This supplementary material shows the annotated trees from BEAST, the .xml files and the .kml files to display the entire time series in Google Earth. See the Zenodo repository (doi:10.5281/zenodo.376190)