Towards an understanding and harnessing of local ecological knowledge of forage resources for sustainable rangeland management in West Africa's Sudanian Savannas

Inaugural - Dissertation

zur

Erlangung des Doktorgrades (Dr. rer. nat.)
der Mathematisch-Naturwissenschaftlichen Fakultät der Universität zu Köln

vorgelegt von

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Köln, 2016

Gedruckt mit Genehmigung der Medizinischen Fakultät der Universität zu Köln 2017

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Tag der letzten mündlichen Prüfung: 28. November 2016.

"Adhering to a daily schedule that is led by your vision and run by your priorities is the surest path to personal freedom." – Mark Ford

Dedication

This dissertation is dedicated to:

- My wife: **Rosemary Naah**, and
- Children: **Terence N. Naah, Gabriel Y. Naah** and **Michelle N. Naah**,

……………………for their immense understanding, love and patience during my field visits, data analysis and write-up stages of this thesis document.

General abstract

Despite the fact that dryland savanna ecosystems provide a host of essential ecosystem goods and services to both humans and livestock, they are often confronted with dangerously vacillating levels of locally available natural resources to support rural livelihood strategies in the face of increasing anthropological influences and global climate change impacts. This points to the vital roles which the socio-cultural and bio-physical environment sub-systems play to ensure the stability of the complex socio-ecological system (SES). Several attempts have been made in the past to focus more on scientifically-based means of investigation than including contributions of the local resource users to better understand and harness SES. Notwithstanding, local ecological knowledge (LEK), which is an effective, investigative tool for understanding interactions between the ecological and social sub-systems of complex SES, has recently received increasing attention in studies on the effects of climate and land use changes on the availability and utilization of natural resources in communal rangelands. Surprisingly, little is still known when it comes to LEK of forage resources, particularly in the West African Sudanian Savannas.

The overarching goal of this study was to investigate local agro-pastoralists' knowledge on forage resources used by cattle, goats and sheep and how they adapt their rangeland management strategies to vegetation dynamics. I hypothesized that LEK can potentially provide insight into reasons how and why forage resources are overexploited, and into management strategies to conserve or restore them. The study encapsulates three major empirical components: (i) LEK distributional patterns in forage resources utilization (Chapter 4), (ii) local valuation criteria for forage resources (Chapter 5), and (iii) local perceptions on forage species diversity, abundance trends, habitats distribution and ecological drivers to forage species changing trends over the past few years via the 'lenses' of local agro-pastoralists (Chapter 6). Using a stratified random sampling approach, I sampled sixteen villages across three dominant socio-linguistic groups and a steep climatic aridity gradient in both Ghana (seven villages) and Burkina Faso (nine villages) to address the aforementioned empirical components of the study. Although individual ethnobotanical interviews were chosen over focused or group discussions to extract the bulk of independent primary ethnobotanical data from local agro-pastoralists,

I also complemented the data collection process with personal observations and ethnobotanical walks for purposes of triangulation.

For the distributional patterns of LEK on forage resources utilization among local agro-pastoralists, this thesis examines socio-cultural and environmental variables which specifically affect various components of LEK dynamics (be it LEK on herbaceous, woody and crop-related forage plants), reflecting their capacity to recollect and list vernacular names of forage species. This section also looks at the local climatic variability implications for LEK accumulation on forage plants (Chapter 4). Furthermore, this study addresses the aspect of local valuation criteria for forage resources by agro-pastoralists. Here, I elicited LEK on forage resources by asking them to cite and rank specific forage species mostly considered to be palatable for various domestic livestock and at different seasons. I also asked agro-pastoralists' to provide underlying reasons for their rankings to gather more information on explicit valuation criteria for available forage resources. This anthropological dataset was matched with ecological information obtained from rangeland vegetation sampling using 20m x 50m per plot for the woody vegetation at different topographic positions (Chapter 5). Regarding local perceptions on forage species diversity, abundance trends, habitat distributions and ecological drivers, local agro-pastoralists were interviewed to specifically answer questions relating to above-stated ecological variables (Chapter 6).

To disentangle the effects of socio-cultural and environmental variables on LEK accumulation and local explicit valuation criteria, I employed various statistical approaches such as exploratory data analyses with IBM SPSS v. 22 as well as generalized linear mixed-effects models (GLMM) with rigorous model selection procedures using the Akaike Information Criterion (AIC) with R software (Chapters 4 & 5). I also used non-metric multi-dimensional scaling (nMDS) to visualize similarities or dissimilarities of LEK distributional patterns as well as a two-way non-parametric permutational multivariate analysis of variance (PERMANOVA) using PC-ORD v.5 for purposes of triangulation (Chapter 4). Also, I used ANTHROPAC 1.0 software to calculate cognitive salience index (CSI) of both anthropological and ecological datasets. In Chapter 6, the forage species diversity metrics were estimated and other ecological variables done

using descriptive statistics, bivariate correlation analysis and also performed CSI calculations.
The results of this study reveal that those who resided in villages with moist environmental conditions seem to generally exhibit superior LEK on forage resources in terms of citation of many forage species than those who situate in dry rural communities. This evidence also is true for the ability of local agro-pastoralists to provide various underlying reasons for ranking of cited forage species. It was also evident that local agro-pastoralists possessed extensive knowledge and understanding of the habitat distribution, abundance trends and effects of predominant ecological drivers in the study region. The findings of this study, therefore, contribute to the on-going scholarly debates on how LEK-oriented research is crucially important, and the need to incorporate it into the scientific approach to enhance the functional understanding of ethno-ecologically useful natural resources for sustainable development and livelihood improvement.
Key words: Agro-pastoralists; Burkina Faso; Dryland rangelands; Forage resources; Ghana; Local ecological knowledge; Social-ecological systems; Valuation criteria.

Zusammenfasung

Die Savannen-Ökosysteme Afrikas liefern wichtige Ökosystemdienstleistungen für Mensch und Tier. Vor dem Hintergrund der zunehmenden anthropogenen Überformung und des Klimawandels werden die entsprechenden natürlichen Ressourcen jedoch knapper, was die lokalen Überlebensstrategien der Menschen nachhaltig beeinflusst. Die sozio-kulturellen und biologisch-physischen Subsysteme der Umwelt, die eine wichtige Rolle im sozio-ökologischen System (SES) spielen, werden deshalb immer bedeutender. In der Vergangenheit wurden verschiedene Versuche unternommen, das System der Ökosystemdienstleistungen besser zu verstehen und nutzen zu können. Jedoch lag der Fokus dieser Analysen vor allem auf wissenschaftlich begründeten (externen) Untersuchungs- und Bewertungsmethoden, während lokale Praktiken und Erfahrungen der Nutzer der Systemdienstleistungen kaum einbezogen wurden.

Ungeachtet dessen hat das Interesse an lokalem ökologischem Wissen (Local Ecological Knowledge, LEK) und dessen Erforschung in jüngster Zeit deutlich zugenommen. Nicht zuletzt ermöglicht der LEK-Ansatz ein umfassenderes Verständnis der Prozesse zwischen ökologischen und sozialen Subsystemen, etwa bei der Analyse der Auswirkungen von Klimawandel und Landnutzungsveränderungen auf die Verfügbarkeit und Nutzbarkeit der natürlichen Ressourcen von Weideland. Von besonderem Interesse sind dabei die Savannengebiete der Sudanzone West-Afrikas. Überraschenderweise ist dort bisher allerdings erst sehr wenig Forschung über LEK im Bereich der Nahrungsmittelressourcen betrieben worden.

Das Hauptziel dieser Arbeit liegt in der Analyse des lokal verfügbaren Wissens von Viehhaltern über die natürlichen Ressourcen der Weideländer, die für Rinder, Ziegen und Schafe genutzt werden. Darüber hinaus sind die Anpassungsstrategien in der Weidewirtschaft in Bezug auf die Vegetationsdynamik von besonderem Interesse. Der Studie liegt die Hypothese zugrunde, dass LEK einen wichtigen Beitrag zur Erforschung der Gründe und des Ausmaßes der Überbeanspruchung von Weideland leisten kann und darüber hinaus wertvolle Ansätze zum Aufbau von nachhaltigen Ansätzen der Weidebewirtschaftung liefert.

Die Studie setzt sich aus drei empirischen Komponenten zusammen: 1. Analyse der Verbreitung und Anwendung von LEK bei der Nutzung von Weidelandressourcen (Kapitel

4), 2. Analyse lokaler Bewertungskriterien von Weidelandressourcen (Kapitel 5) und 3. Analyse der lokalen Wahrnehmung von Artenvielfalt, -reichtum und -verbreitung sowie der ökologischen Faktoren der Veränderungsprozesse aus Sicht von Weidelandnutzern (Kapitel 6).

Für die Analysen wurden 16 Dörfer mittels geschichteter Stichproben als Untersuchungsgebiete ausgewählt. Diese erstrecken sich entlang der Verbreitungsräume von drei größeren sozio-linguistischen Gruppen sowie eines abnehmenden Ariditätsgradienten in Ghana (sieben Dörfer) und Burkina Faso (neun Dörfer). Für die Erhebungen wurden individuelle enthnobotanische Interviews gewählt, um eine große Fülle an ethnobotanischen Primärdaten von lokalen Viehhaltern erfassen zu können. Diese wurden durch persönliche Beobachtungen sowie ethnobotanische Begehungen ergänzt, um die gewonnen Daten triangulieren zu können. Im Rahmen dieser Dissertation wurden sowohl sozio-kulturelle als auch ökologische Variablen erhoben, um die verschiedenen Effekte der Komponenten auf die LEK-Dynamik im räumlichen Kontext erfassen zu können. LEK wird im Hinblick auf Kräuter sowie Holz- und Erntepflanzen untersucht – dabei wurden vor allem die Fähigkeiten der Menschen erhoben, einheimische Pflanzen zu lokalisieren und zu benennen. Dieser Teil der Studie untersucht auch die Implikationen der lokalen klimatischen Variabilität auf die LEK-Akkumulation in Bezug auf Weidelandpflanzen (Kapitel 4). Darüber hinaus betrachtet die Dissertation die lokalen Bewertungskriterien für Weidelandressourcen von Viehhirten. Hierfür wurde das vorhandene LEK überprüft, indem die Befragten verschiedene Pflanzenarten benennen, in eine Rangfolge bringen und nach ihrer Nutzbarkeit zur Tierernährung bewerten sollten. Zudem wurde jeweils nach einer Begründung für die Bewertung gefragt, um mehr Informationen über die entsprechenden Kriterien sammeln zu können. Dieser ethnologische Datensatz wurde auf Übereinstimmung mit ökologischen Faktoren untersucht. Als Grundlage hierfür wurde die Vegetationszusammensetzung für Plots von 20m x 50m in unterschiedlichen topographischen Positionen erfasst (Kapitel 5). Zudem wurden Viehhirten zu ihrer Wahrnehmungen von Diversität und Verbreitung von Weidelandpflanzen sowie den zugrunde liegenden ökologischen Einflussfaktoren befragt (Kapitel 6).

Um die sozio-kulturellen und ökologischen Effekte des LEK sowie lokale Bewertungskriterien zu bestimmen, wurden mithilfe von IBM SPSS v. 22 statistische Berechnungen

durchgeführt. Mit R konnten „Generalized Linear Mixed-Effects Models“ (GLMM) mit diskreten Modellauswahlprozeduren auf der Basis des Akaike Information Criterion (AIC) berechnet werden (Kapitel 4 und 5). Für die Visualisierung von Ähnlichkeiten und Unterschieden des LEK wurde eine nicht-metrische multi-dimensionale Skalierung (nMDS) sowie eine nicht-parametrische multivariate Analyse (PERMANOVA) mithilfe von PC-ORD v.5 durchgeführt. Mithilfe von ANTHROPAC 1.0 wurde der „Cognitive Salience Index“ (CSI) der ethnologischen und ökologischen Daten berechnet. In Kapitel 6 werden Messwerte für die Diversität der Weidepflanzen abgeschätzt und weitere ökologische Variablen mittels deskriptiver Statistiken, bivariater Korrelationsanalysen und CSI-Berechnungen ermittelt.

Die Ergebnisse der Studie zeigen, dass Viehhalter in Dörfern mit feuchteren Umweltbedingungen über mehr Wissen in Bezug auf die Benennung von Pflanzennamen verfügen als dies bei Hirten in trockeneren Gebieten der Fall ist. Dieser Unterschied wird bei der Fähigkeit der Viehhirten bestätigt, eine Begründung für ihre Bewertungskriterien von Nutzpflanzen benennen zu können. Ebenfalls ist evident, dass Viehhirten ein stark ausgeprägtes Wissen über lokal vorkommende Pflanzenarten und ihre Verbreitung haben. Zudem können sie Entwicklungen von Verbreitung und Vorkommen abschätzen sowie ökologische Faktoren hierfür benennen.

Die Ergebnisse dieser Studie leisten einen Beitrag zur fortlaufenden wissenschaftlichen Debatte um LEK-basierte Forschung. Sie bestätigen zudem die hohe Relevanz entsprechender Untersuchungen und Notwendigkeit, diese in zukünftige Ansätze zur Nachhaltigkeitsforschung einzubinden.

Schlusselwörter: Viehhalter; Burkina Faso; Ghana; Trockengebiete; Nahrungsmittelressourcen; Lokales ökologisches Wissen; Sozio-Ökologische Systeme; Bewertungskriterien.

Acknowledgements

I hereby, first of all, express my profound indebtedness to Prof. Dr. Boris Braun who took over the primary supervision of my thesis work at its advanced stage. I am very thankful to him for his academic guidance, open-mindedness, a warm welcome to his working group and provision of office space and financial support by engaging me as a graduate research assistant at the Institute of Geography. This offered me an enabling environment to be more concentrative and productive to ensure swift finalization of my thesis. I am equally thankful to my second supervisor, PD Dr. Anja Linstädter, who previously provided me a research opportunity in her working group and guided me to shape and enrich my research work. Many thanks also go to my academic tutor at the Center for Development Research (ZEF), Dr. Irit Eguaveon, for her valuable academic advice and involvement at the onset of my research process.

I also duly acknowledge the German Federal Ministry of Education and Research (BMBF) for the provision of funding for my research activities via the West African Science Service Center on Climate Change and Adapted Land-use (WASCAL; FKZ 01LG1202A). I also express my appreciation to all WASCAL staff, especially Dr. Boubacar Barry and Mr. Boukare Ouedraogo, at the WASCAL Competence Center, Ouagadougou for logistical support. Let me also particularly thank Mr. Aaron Aduna, WASCAL coordinator at the Bolgatanga Basin, for his readiness to render logistical support and general accommodation needs despite obvious challenges during field visits in Ghana.

I would like to also convey my deepest and sincere gratitude to the dean of the graduate school at the Faculty of Mathematics and Natural Resources, Prof. Dr. Günter Schwarz, who patiently listened to my academic grievances and encouraged me with his pieces of advice to be able to finish the thesis write-up.

I also want to deeply acknowledge the following persons: Dr. Guido Lüchters, Dr. Jan Ruppert, Dr. Justice Tambo and Mr. Frederik Aust for making useful statistical inputs at the initial stages of my data analysis. Additionally, I am very thankful to Dr. Reginald T. Guuroh for his brotherly support and constructive discussions. My interactions with these people highly strengthened my statistical knowledge and equipped me with new skills and experiences. I am also very grateful to Dr. Gerald Forkuor and Mr. Müller Maximilian for editing the map of my study area and German translation of the general thesis abstract

respectively. My thanks also go to all members of my new working group of Prof. Dr. Boris Braun, especially Mr. Abdullah Al-Maruf and Mr. Sebastian Fastenrath, both PhD candidates, for good company and useful discussions. I also want to take this opportunity to acknowledge the immerse institutional support received from the Université de Ouagadougou, Burkina Faso (e.g. Dr. Oumarou Ouedraogo, Mr. Cyril), regarding assistance in the identification of herbarized forage plants specimen, Ministry of Food and Agriculture (MoFA) staff in Bolgatanga office (e.g. Mr. J. B. Walier), Ghana, for information on crop and livestock production and the Senckenberg Institute staff (e.g. Dr. Marco Schmitz) at the University of Frankfurt, Germany, for confirmation of scientifically identified forage plants specimens.

My acknowledgements are not complete without the mention of local agro-pastoralists and traditional leaders (chiefs) who generously allowed me and the research team to interview them on LEK of woody-, herbaceous- and crop-related forage plants. These interviews provided a lot of insight into how ethnobotanical knowledge was popular and accumulated among the local folks. Despite a lot of inter- and intra-dialectical challenges encountered during the interview sessions, my local field assistants painstakingly performed creditably well in helping me collect the required data (both anthropological and ecological datasets) for this final thesis work. I am, therefore, highly indebted to them: Mr. Francis-Xavier Naawaakuo, Miss Cynthia Kuubari and Mr. Simon Aboona in Ghana and Mr. Vincent Bado, Mr. Kassim Millogo, Mr. Zou Abdoul Lamine and Mr. George Kowe in Burkina Faso. I am equally grateful to Mr. Bado Romeo at the WASCAL Competence Center, Ouagadougou, for monitoring and coordinating some field interviews conducted within the Ouagadougou environs in my absence. I also thank Mrs. Abena Adu-Sarpong for her encouragements as well as Pastor Yeboah Ebenezer and Mr. Stephen Boseah for their prayers in some difficult moments encountered in the course of my study. Many thanks equally go to my parents (Mr. Yakara Naah and Mrs. Yirifaah Naah) and siblings for their immense moral support, love and prayers throughout my academic life.

Most importantly, thanks be to the almighty God for His divine guidance, blessings and protection throughout my entire study period and in other areas of endeavor. May the good Lord richly bless you all.

N.B.:

I. For the three empirical Chapters of this study, two Chapters (4 & 5) have been submitted to internationally recognized scientific Journals namely Journal of Environmental Management and Agriculture, Ecosystems and Environment.

II. The two submitted manuscripts have been mainly written by the doctoral candidate (first author). The respective co-authors (Reginald T. Guuroh, Anja Linstädter and Boris Braun) made inputs before submission to Journals for consideration for publication.

III. The third empirical Chapter (6) is currently prepared in readiness for submission soon to a Journal.

IV. The doctoral candidate has been publishing under slightly different surname (**Naah**) instead of (**Naah Ngmaadaba**) reflecting in his official documents to avoid confusion in the citation of his scientific publications by other scientists.

V. The pronoun, ‘we’, is used in some Chapters to refer to the doctoral candidate and others (co-authors).

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Abbreviations

AEZ	Agro-ecological zone
AI	Climatic aridity index
AIC	Akaike information criterion
ANOVA	Analysis of variance
CI	Confidence interval
Cri_{cattle}	Local valuation criteria for cattle
Cri_{DS}	Local valuation criteria in the dry season
Cri_{goats}	Local valuation criteria for goats
Cri_{RS}	Local valuation criteria in the rainy season
Cri_{sheep}	Local valuation criteria for sheep
CSI	Cognitive salience index
CSOs	Civil Society Organizations
DSA	Dry semi-arid
DSH	Dry subhumid
E	Species evenness
EAH	Ecological apparency hypothesis
FAO	United Nations Food and Agriculture Organization
For_{crop}	Crop-related forage resources
For_{herb}	Herbaceous forage resources
For_{wood}	Woody forage resources
GLMM	Generalized linear mixed-effects models
H`	Shannon Wiener diversity index
HUM	Humid
IK	Indigenous knowledge
LEK	Local ecological knowledge
MOFA	Ministry of Food and Agriculture
MSA	Moist semi-arid
NDVI	Normalized Difference Vegetation Index
nMDS	Non-metric multidimensional scaling
PCA	Principal component analysis

S	Species richness
SDI	Simpson’s diversity index
SES	Socio-ecological systems
SPSS	Statistical Package for the Social Sciences
TEK	Traditional ecological knowledge
UNEP	United Nations Environmental Program
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use

1 General introduction

The scientific body of literature abounds with evidences that future projections and scenarios of global climatic conditions point to increasing incidences of drought spells, overgrazing, severe temperatures and land degradation particularly in global drylands (IPCC 2007, Reynolds et al. 2007, Maestre et al. 2012, IPCC 2013), and such changes are unbeneficial (IPCC 2013). Drylands (see Section 2.1 for a detailed overview) are also well known to cover the majority of the world's poorest of the poor, including Sub-Saharan Africa, where people largely engage in rain-fed agriculture as their main source of employment, food and income (SWAC/OECD 2008). The general notion that drylands are of little value does not reflect the reality (Maestre et al. 2012). This is because, drylands are believed to provide a wide range of ecosystem goods and services for humans' well-being in many parts of the world (MEA 2005, Maestre et al. 2012, Rinawati et al. 2013).

It is also argued that the livelihood security of the majority of people inhabiting these dryland ecosystems is largely dependent upon the provision of ecosystem services from local vegetation (Martin et al. 2016). For instance, forage services (Duru et al. 2015) serve as the most important provisioning ecosystem services in tropical savannas (Safriel and Adeel 2005). The delivery of these forage services from dryland rangelands is mainly dependent on rangelands' floristic composition (Anderson et al. 2007, Linstädter and Baumann 2013), but modulated by other drivers such as recent precipitation (Wiegand et al. 2004, Ruppert et al. 2012). The floristic composition itself is driven by various abiotic and biotic factors, with climatic aridity being among the most prominent one on a regional scale (Linstädter et al. 2014). Hence, climate is a critical factor for the delivery of forage services, and climate change may exert a strong influence on them (Ferner et al. 2015).

In typical West African settings, continued forage availability for livestock production is highly crucial since about 45 percent of rural households (mostly practicing agro-pastoralism) heavily rely upon sources of livestock-related income (Mertz et al. 2010). Notwithstanding, the majority of the local agro-pastoralists in this region, as in other drylands of the globe, are often confronted with a multiplicity of other challenges such as pests and diseases, scarcity of water and limited forage resources, high poverty levels, increasing human population growth, land use pressure coupled with the negative impacts of global environmental change over the past decades (SWAC/OECD 2008). In spite of these daunting challenges usually faced by local farmers in such dry environments, they have been able to cope and adapt to the rapidly changing climatic conditions in their local vicinities for several year (Mortimore and Adams 2001). Fortunately, negative effects of climate change on forage service delivery – and thus on local livelihoods – may be partly mitigated by an adaptive rangeland management (Martin et al. 2014). For example, management decisions can be attuned to the vulnerability of forage plants, creating rest periods in times when forage plants are particularly sensitive to grazing (Buttolph and Coppock 2004, Müller et al. 2015). To be able to do this, local agro-pastoralists have to draw upon their accumulated local wisdom from many generations to sustainably managing these limited natural forage resources for their livestock and their own survival. These considerations underline the fact that land users' local ecological knowledge (hereafter also LEK) on forage plants is of critical importance for an adaptive rangeland management (Müller et al. 2007, Linstädter et al. 2013).

A plethora of literature shows that LEK has received growing levels of international recognition in studies on the effects of climate and land use changes, species richness and vegetation composition in communal rangelands (Berkes et al. 2000, Steele and Shackleton 2010). However, these studies mostly focused on mobility decisions (Adriansen 2008, McAllister 2010), and/or on other aspects of agro-pastoral systems, such as degradation patterns or drought management (Homann et al. 2008, Ifejika Speranza et al. 2010, Kgosikoma et al. 2012, Oba 2012).

LEK on forage plants is being considered as a crucially vital tool for understanding social-ecological systems (SES; see Section 2.2 beneath for details). The few studies explicitly addressing the cultural domain of forage plants come from Brazil (Nunes et al. 2015), Ethiopia (Bahru et al. 2014), and Morocco (Linstädter et al. 2013). These studies underline that dryland pastoralists have indeed a rich body of forage-related LEK, and that it plays a key role for management decisions (Linstädter et al. 2013). To the best of my knowledge, investigations regarding use of LEK on forage resources within the West African Sudanian savannas (particularly Ghana and Burkina Faso) has been highly under-documented and poorly understood. Not only has this research rekindles the importance of LEK investigations in the context of SES generally but also serves as a stepping stone for deeper understanding of how locally available forage resources are being sustainably used over the years by local agro-pastoralists in the study area.

In this thesis, I do not only look at a limited dimension of LEK on forage resources but rather aim to explore a wide array of LEK on woody vegetation, herbaceous plants and crops (including crop residues) for sustainable domestic livestock production among small-householder agro-pastoralists inhabiting rural communities in northern Ghana and southern Burkina Faso. The most commonly farmed large- and small-stock namely cattle (*Bos taurus L.*), goats (*Capra hircus L.*) and sheep (*Ovis aries L.*) are considered in this study (see Fig.1). The Sudanian zone of both countries is inhabited by a large number of small ethnic groups and thus show different socio-economic conditions and different forms of natural resource management within the same agro-ecological zone.

Using stratified random sampling in my methodological approach (see Chapter 3), the villages of interest together with local informants, belonging to different dominant ethnic groups as well as gender affiliations and age categories, were meticulously chosen along a steep climatic gradient of increasing aridity from South to North (see Figs. 4, 9, 13). This was primarily done to examine and extract drivers of local agro-pastoralists' knowledge accumulation, identify local valuation criteria for forage resources ranking and assess their knowledge perception of forage species diversity, abundance, habitat distributions and ecological drivers responsible for their changing trends along a delineated aridity gradient and variegated socio-cultural backgrounds in a typical West African settings.

I argued that LEK accumulation, valuation criteria of forage resources and local perception of forage species diversity, distribution, abundance and ecological drivers are differentially influenced by climate-related and socio-demographic variables. This study also argues that local knowledge in conjunction with ecologically scientific knowledge on available natural forage resources is of utmost importance to sustainable rural agro-pastoralism, contributing to the on-going debate about the vital role LEK investigations play for various aspects of natural resources management, especially in Ghana and Burkina Faso. The output of this research is geared towards shedding some new light on the depth of local agro-pastoralists' LEK on the under-studied forage resources to understand and harness how to effectively dialogue with local community members and policy-makers for sustainable rural livelihood improvement.

Fig. 1: Predominant domestic livestock types (I) and forage resource types (II) considered within typical West African Sudanian Savanna ecosystems. Note: Livestock types considered in this study are only limited to cattle, goats and sheep, while forage resource types are not limited to those displayed in the photos.

1.1 Definition and usage of basic terminologies

To enhance the understanding of the rich LEK on forage resources used for domestic livestock from the perspective of local agro-pastoralists, I define and used the following terminologies in this thesis document:

- **Forage resources** are hereby referred to a broad array of plant materials such as woody vegetation (trees and shrubs), herbaceous plants (annual- and perennial grasses and forbs) as well as crop plants (and/or crop residues) used to feed domestic livestock especially cattle, goats and sheep reared in communal rangeland settings.
- Followinng Dougill et al. (2012), **rangelands** refer to terrestrial ecosystems which are constrained by environmental stressors such as droughts, fire and severe temperatures and mostly dominated by herbaceous and shrubby vegetation. With such an open savanna vegetation structure, dryland rangelands are suited for rearing of domestic livestock to make use of locally available forage resources. Here, rangelands are largely communal grazing areas which are also fallowlands.
- **Local agro-pastoralists** are those peasant farmers (including their family members) who engage in both crop farming (food and cash crops) as well as livestock husbandry (large and small domestic ruminants and poultry) for survival. Agro-pastoralism is mostly practiced in selected villages for this study.
- **Local pastoralists** are those local farmers whose household needs come from 50 percent or more livestock or animal-related products for consumption (Niamir-Fuller 1998). In the studied rural communities in northern Ghana and southern Burkina Faso, pastoralism is not strictly practiced.
- The terms **"local informants", "local respondents", "local experts" and "local farmers"** are used in this study to depict local inhabitants who have in-depth

understanding and knowledge of forage plants available on their immediate environs through their own practical experiences over the years.

- **Traditional ecological knowledge (TEK)** is defined as a cumulative body of traditional knowledge, practices, and beliefs via evolving adaptive processes which have been passed down from generation to generation by cultural transmission and the relationship of living organisms with their natural environment (Berkes et al. 2000).
- **Indigenous knowledge (IK)** refers to the knowledge and perception of the local environment by indigenous people at a particular locality.
- **Social-ecological systems (SES)** refers to the interplay between humans and their natural environment in a complex and adaptive manner. The provision of ecosystem services from the natural environment have been coupled with societal feedback in SES studies (Nassl and Löffler 2015).
- The term **"local ecological knowledge (LEK)"** is defined here as the experiential knowledge obtained from a given group of local resource users about their local ecosystems. As clearly argued by Olsson and Folke (2001), LEK, which is a mixture of scientific and practical knowledge, site-specific as well as a belief system, differs from that of TEK/IK, which takes into account the 'historical and cultural continuity of resource use'.

From the above definitions, the term "local agro-pastoralist" is used often in this document to reflect agro-pastoralism as the commonly practiced agricultural production system by local people in the target communities of this study. As per the focus of this research study, the forage situation is considered similar for both agro-pastoralists and pastoralists, and so both terms are used interchangeably, although the 'local agro-pastoralists' is used more frequently in this study. Also, the terms "local informants", "local respondents", "local experts" and "local farmers" are used interchangeably especially in the methodological part of this study, to depict the same group as 'local agro-pastoralists'. Additionally, looking at the definitions of LEK, IK and TEK, the former is consistently used in this thesis throughout instead of the other related terminologies for the sake of clarity. Land users may not necessarily be only indigenous people but all local resource users living in such localities for a considerable period of time, as also asserted by Berkes et al. (2000) and Huntington (2000).

1.2 Rationale for this LEK study

Humans and nature do co-exist for mutual benefits since time immemorial. Thus, recording LEK is a useful approach to understand interactions between the subsystems of complex SES (see Section 2.2). An integration of social science dimensions of LEK into scientifically-based ecological research in many disciplines for maintaining the sustainability of SES functioning has been suggested (Ostrom 2009, Roba and Oba 2009, Reed et al. 2011). This would then lead to a continued provision of ecosystem services for various uses (Berkes et al. 2000, Pierotti and Wildcat 2002, Thomas and Twyman 2004). Nonetheless, its integration into science is still hampered by the lack of formalized and rigorous scientific methods and concepts (Da Cunha and De Albuquerque 2006). In the past years, there have been some promising attempts for LEK integration into ecological investigations (Reed et al. 2008, Wesuls and Lang 2010, Linstädter et al. 2013).

In analogy to the rapid loss of the genetic diversity of useful plants, cultivars or livestock breeds, LEK may also be rapidly lost in situations of economic and cultural change (Gaoue and Ticktin 2009, Koohafkan and Cruz 2011). Thus, the loss of LEK on natural resources and their management, including potentially adaptive strategies to changing climatic conditions, poses a great threat to our future ability to cope with or mitigate negative consequences of climate change in rangelands worldwide (Koohafkan and Cruz 2011). It is thus surprising that the value of LEK has so far received little attention in studies on the effects of climate change on livelihood security (Mertz et al. 2009) as well as on forage resource supply and use. Although LEK studies have recently received increasing interest from several contemporary scientists in the face of global environmental change (Berkes et al. 2000, Steele and Shackleton 2010), little is still known about forage-related LEK in the Sudanian savannas of West Africa. The need to systematically extract and document supremely important information from local people’s LEK on the declining forage resources for sustainable livestock production is, among others, the compelling reason for this ethnoecological inquiry. This is particularly crucial because LEK (for that matter, TEK) is hardly written down and being quite difficult to access (Huntington 2000). This, therefore, makes it very vulnerable and easy to be lost in the face of social, economic and technological changes in today's globalized village if not well documented.

1.3 Research goal and specific objectives

The overarching goal of this study is to investigate, understand and harness agro-pastoralists' LEK of forage resources regarding their availability, quality and management strategies in West Africa's Sudanian savannas to cope and/or mitigate negative consequences of climate change (e.g. increased variability in the frequency and severity of rainfall, and declining forage resources) on agro-pastoralists' livelihoods. In carrying out this forage-related LEK research, three broad empirical objectives and associated hypotheses were formulated as follows:

1. To evaluate drivers (climate-related and socio-demographic variables) influencing agro-pastoralists' LEK accumulation on forage resources along a steep West Africa's aridity gradient (see Chapter 4 for more details).
2. To investigate local criteria used by local agro-pastoralists for the valuation of forage resources ranked for common domestic livestock types (see Chapter 5 for more reading).
3. To assess local agro-pastoralists' perceptions of forage species diversity, habitat distribution and ecological drivers to changing abundance trends of forage plants for sustainable livestock management in the West African Sudanian savannas (see Chapter 6 for more details).

1.4 The organizational structure of the thesis

The structure of this thesis entails seven major Chapters. The first Chapter covers the general introduction, under which the research rationale, goal and specific objectives, and definitions of basic terminologies are presented. To put this study in broader context, the second Chapter explicitly deals with a brief overview of global dryland rangelands and the conceptual framework of socio-ecological systems (SES). The third Chapter encompasses general materials and methods. This Chapter specifically looks at methods in rangeland vegetation ecology, ethnobotanical methods commonly used in investigating local knowledge and broad methodological framework of this research study. Moreover, a description of the study area focusing on the environmental (climate, geology and pedology, vegetation, floral and faunal species) and cultural settings (socio-linguistic membership, local land use systems, etc.) will be provided. Still under this Chapter, I also explain the study and sampling designs together with personal observations and ethnobotanical walks for purposes of triangulation. The challenges of ethnoecological research encountered during fieldwork are also covered under this Chapter. The fourth Chapter takes a focused look at the dynamics of LEK accumulation among local pastoralists inhabiting along a step climatic aridity gradient. I discuss and draw conclusions regarding the results on the importance of ethnicity and aridity variables for shaping quantitative LEK distributional patterns and implications of local climate change for LEK of forage resources. In the fifth Chapter, I employ an in-depth quantitative ethnoecological approach to identify explicit local valuation criteria of forage resources from the perspectives of local agro-pastoralists. The sixth Chapter dovetails on local agro-pastoralists' perceptions of forage species diversity, abundance, habitat distribution and ecological drivers to their changing trends in the West Africa's Sudanian Savanna. The findings of this part of the study undergo rigorous statistical analyses, and are discussed in line with sustainable natural resources management in the face of changing climatic conditions and corresponding conclusions provided. Lastly, the seventh Chapter is concerned with the prospects of these forage-related LEK findings and future research needs including conclusions and recommendations.

2 Conceptual framework of this study

2.1 Global drylands: A brief overview

Drylands constitute approximately 41.3 percent of the terrestrial landmass of our planet (MEA 2005). Out of over 40 percent of existing drylands worldwide (see Fig. 2), 72 percent lie in developing countries (CIESIN FAO & CIAT 2005) while 65 percent of the African continent comprise of drylands (MEA 2005). Although drylands are characterized by different criteria to define aridity and to create climatic boundaries of these areas, the United Nations Environmental Program (UNEP) classification system of climatic aridity is widely accepted and used (UNEP 1997). The dryland ecosystems are known to have an annual potential evapotranspiration greater than the annual precipitation by a minimum factor of 1.5 (Middelton and Thomas 1997). Thus, the aridity index (AI) for drylands is such that AI < 0.65, which further categorized into four classes: hyper-arid (AI < 0.65), arid (0.05 < AI <0.20), semi-arid (0.20 < AI <0.50) and dry sub-humid (0.50 < AI 0.65). Since climatic division are just imaginary, I used the AI calculated for each sampled village and put them into four specific groups. It is recognized in the literature that drylands are not in equilibrium but rather can be distinguished into four broad biomes, namely deserts, grasslands, shrublands and savanna, based upon the varied degree of water scarcity (Maestre et al. 2012). This study is concentrated chiefly on relatively water-constraint semi-arid climate areas in Ghana and Burkina Faso with open savanna vegetation (with AI for individual rural villages; see Section 4.1).

The syndrome of drylands is mainly characterized by high variability in terms of precipitation and other climate factors (temperature, humidity and potential evapotranspiration), low soil fertility for tillage and grazing, sparse human populations, remoteness from markets and distant from the priorities of decision-makers (distant voice), making it difficult for drylands to deliver services effectively and efficiently (Reynolds et al. 2007). Therefore, these drylands are not only vulnerable and sensitive to incidences of desertification as well as social, land-use and institutional changes (MEA 2005, Reynolds et al. 2007, Reed et al. 2012) but also climate change forecasts suggest that such drought-prone drylands will be confronted with hugely severe environmental consequences as compared to non-dry areas worldwide (IPCC 2007). Global drylands are also expanding under climate warming (Feng and Fu 2013). As a result of such biophysical limitations of drylands, they are generally perceived to be unproductive and useless ecosystems from the ecological and socio-economic viewpoints, leading to an erroneous general impression about drylands because they are of paramount relevance to humans for many reasons (Maestre et al. 2012). For instance, dryland rangelands generally support about 50 percent of global livestock production (Allen-Diaz et al. 1996). They support nearly one-third of the world's population (representing ca. 2.5 billion people), 90 percent of whom live in developing countries (Reynolds et al. 2007). Darkoh (2003) stresses that the majority of the world's drylands is used as pastures for domestic livestock production. However, rural populations inhabiting such drought-prone ecosystems are often disadvantaged and tend to be more negatively affected by climate-related impacts and risks are at all levels of development (Niang et al. 2014).

In Africa, agriculture is still the mainstay of the continent's economy. Natural resources – both rain-fed crops and natural forage resources -are highly dependent on variable climatic conditions. At the same time, Africa's natural resource base is under serious threat as a result of high population growth rates, climate and land use change (IPCC 2007, Reynolds et al. 2007). The high degree of inter-and intra-annual rainfall variability in dry areas especially in the West African Sub-region with mainly semi-arid climate is not only attributable to declining forage quality and quantity but also seriously limits other ecosystem provisioning services (MEA 2005). In additional to these challenges, West Africa (especially Ghana and Burkina Faso) like other developing regions, has experienced rapid population growth in the past decades (Mertz et al. 2011). Since institutional arrangements elsewhere may be dysfunctional if imposed on drylands (Reynolds et al. 2007), it is imperative to harness the experiential knowledge from local agro-pastoralists who have managed to use resources for their domesticated livestock over many years in the midst of unpredictable precipitation regimes.

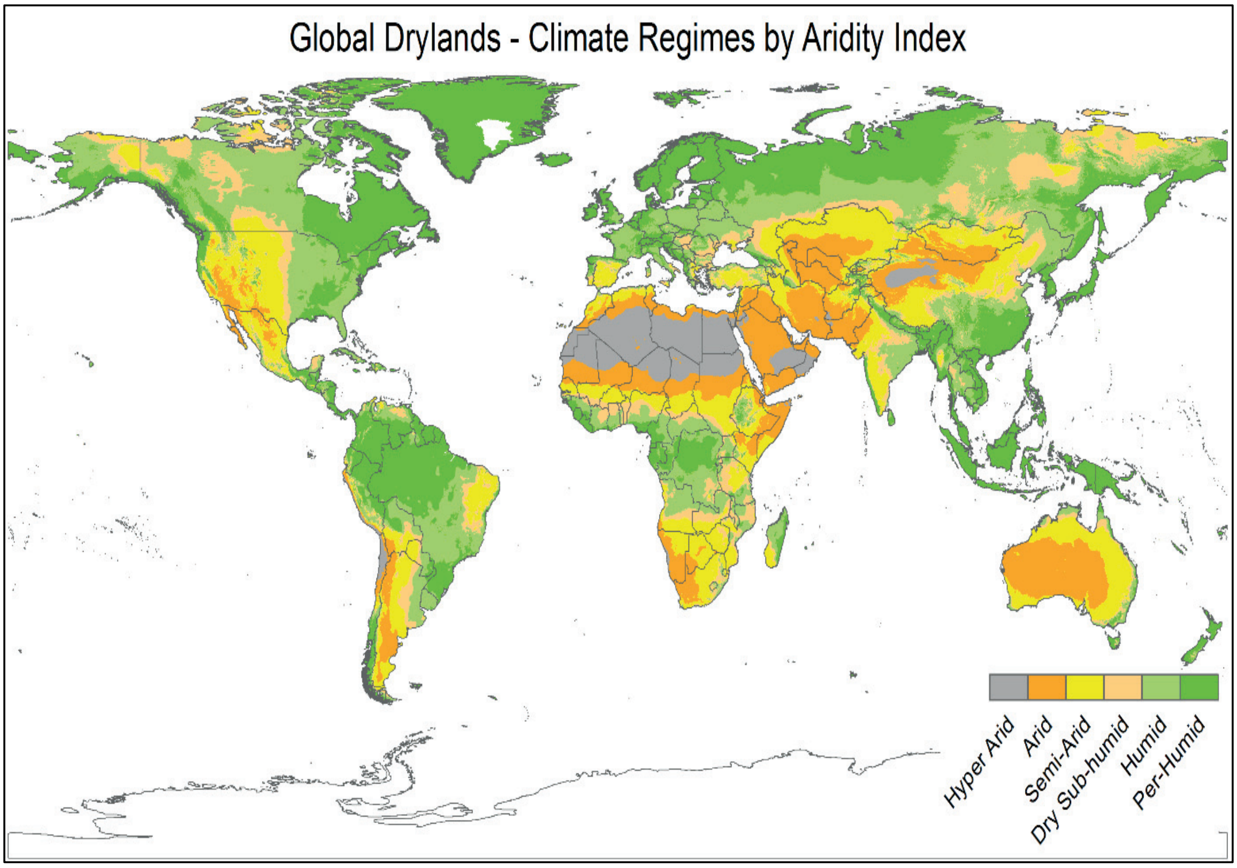

Fig. 2: A map of global drylands illustrating various climatic regimes using the United Nations Education Program (UNEP) aridity classification systems (see Figs. 4, 9 and 13 beneath for locations of specific study sites within the broad study area). Source: MEA, 2005.

2.2 Social-ecological systems as conceptual framework

This research employed the conceptual framework of the complex social-ecological systems (SES) to investigate how LEK on locally available forage resources for the commonly domesticated livestock among local agro-pastoralists in West Africa's communal rangeland can be used to sustainably manage these declining natural resources. Scientific literature on SES theory stresses that, understanding the dynamic interconnections between social and ecological systems is crucial for effective sustainability and biological diversity conservation initiatives (Liu et al. 2007), leading to increased investments in SES research by various governments and foundations (MEA 2005). SES research is rapidly advancing to not only understand the ecological and social conditions but also examine their interactions and outcomes (Berkes et al. 2003, Folke et al. 2005, Ostrom 2009). This is particularly critical for dryland ecosystems where scarce forage resources face frequent incidences of overgrazing, drought spells and negative impacts of global environmental change.

Although drylands are one of the most diverse ecosystems, they still have highly vulnerable SES dynamics (Huber-Sannwald et al. 2012). The complexity of the dynamic transformation in the dryland SES is exacerbated by social, land-use and institutional changes (Reynolds et al. 2007). According to the Inter-governmental Panel for Climate Change (IPCC), most drylands are prone to increased drought intensity and frequency in the near future as predicted in climate change simulations (IPCC 2013). The well-being of humans is hence becoming increasingly threatened by damage to or losses of natural resources (Nassl and Löffler 2015). There is therefore the need for an integrative approach to the socio-economic and ecological domains since social-only or ecological-only research may lead to too narrow conclusions (Folke et al. 2005), reflecting the mutually beneficial human-nature interactions, whereby ecosystem service provision from the natural environment and societal feedback from resource users can be sustainably interwoven for co-adaptation. In the same vein, this ethnoecological inquiry does not only concentrate on the anthropological aspect but also employs vegetation ecology methods (in the following section) to obtain ecological data for better understanding of SES regarding forage resources utilization among local agro-pastoralists. However, Huber-Sannwald et al. (2012) advocate the need to navigate between the challenges and opportunities of anthropogenic land degradation and sustainable livelihood improvement in dryland SES. This reflects the relevance of social-ecological nexus in natural forage resources management. As suggested by Ostrom (2009), studies on SES will not only advance a better understanding of relationships between the social and ecological dimensions but also include their interactions and outcomes. The robust capacities of the local agro-pastoralists to cope with the unpredictable local climatic conditions is demonstrated by the way they endeavor to sustainably manage the scarce forage resources to take care of their domestic livestock.

The resilience thinking in SES research, which includes the three aspects of resilience, adaptability and transformability (Folke et al. 2010), is a pivotal concept to assess the impacts of global change stressors (Ifejika Speranza et al. 2014). However, the assessment of SES resilience in drylands is challenging (Linstädter et al. 2016). Assessments of LEK-related studies in northern and southern Africa on forage plants livestock grazing among rural pastoral households resilience adapt to such challenges for livelihood security (Linstädter et al. 2013, Martin et al. 2016). However, in the West African Sudanian savannas, there is still poor understanding of forage-related LEK from the viewpoint of the local agro-pastoralists, except this study, which investigates on various sources of forage resources such as herbaceous, woody vegetation and crop-related plants for livestock grazing. The main aspects of this study including the climate-related and socio-demographic determinants of distributional patterns of forage-related LEK and local valuation criteria of forage resources as well as local perceptions on ecological variables (e.g. species diversity, abundance trends, habitat types and ecological drivers) have shed more light on the conceptual understanding of SES research.

3 General materials and methods

3.1 Methods in rangeland vegetation ecology

There are several vegetation ecology methods that are employed to conduct research in dryland rangelands worldwide, namely range monitoring, range assessment and range experiments (Baumann 2009). Although dryland rangelands generally have a stochastic nature of available ecosystem services and goods for humans and livestock, they can be 'very good objects of study' in order to better manage them for future generations. In analyzing the impact of grazing on vegetation, some studies have employed ecological methods such as ecological modeling of ecosystem goods such as forage in Southern Morocco (Baumann 2009, Martin et al. 2014) and also remote sensing techniques using the Normalized Difference Vegetation Index (NDVI) to link vegetation dynamics to livestock performance (Pettorelli et al. 2005). For instance, Ferner et al (2015) recently used field spectroscopy to study spectral indicators of forage quality in the West African Sudanian savannas. Thus, investigation methods used in range science do often adopt an interdisciplinary approach (Baumann 2009), whereby methods of vegetation ecology are combined with anthropocentric methods in rangeland management. In this study, an inventory of forage species available in the neighboring local environments of the selected ethnic groups was undertaken via vegetation sampling techniques coupled with ethnobotanical methods commonly used in LEK studies (outlined in the following Chapter). This was done to match LEK on forage resources exhibited by local agro-pastoralists with those sampled via vegetation sampling for purposes of triangulation.

3.2 Ethnobotanical methods for investigation of LEK-related studies

The discipline of ethnobotany is regarded as a multidisciplinary endeavor, involving common fields of botany, economics, anthropology, ecology, ethnopharmacology and linguistics (Martin 2004, Sop et al. 2012). To be able to carry out a basic documentation of LEK and quantitatively evaluate the use and management of plant resources (Martin 2004), researchers should be able to employ a blend of techniques from the afore-mentioned disciplines to perform LEK investigations in given communities. Most importantly, ecologists should be aware of the variety of methods available and their strengths and weaknesses for promoting substantive interchange between local experts and outside scientists (Huntington 2000). A number of methods for documenting TEK (and for that matter LEK) which ecologists often derive from social sciences include semi-directive interviews, questionnaires, analytical workshops and collaborative field work. These methods are not mutually exclusive but rather used to suite what researchers want from target rural communities (Huntington 2000). Rapid ethnobotanical appraisal (Martin 2004) is also a means to rapidly take inventory of biological resources at sites for purposes of environmental impact assessment, particularly at the onset of an ethnobotanical study. To systematically elicit LEK on forage resources from local agro-pastoralists across different ethnicities and climatic conditions in the studied countries, we mainly conducted individually-based ethnobotanical surveys via structured questionnaires administration (see Subsection 5.2.1 for more details).

Local knowledge on the natural environment may greatly benefit range ecologists as it provides an alternative source of information to the conventional scientific understanding (Huntington 2000). Thus, local inhabitants perceive the vegetation to be of high demand for food and used as forage for livestock production (Baumann 2009). LEK is, therefore, a crucially important approach to understanding the interrelationship within the complex and dynamic functioning of SES. This study, unlike other ethnobotanical studies in the region, focuses on LEK of forage resources among the local agro-pastoralists in the West African Sudanian Savannas in order to throw more light on sustainable utilization of the declining natural forage resources. As part of the individually based ethnobotanical questionnaires administered to the local agro-pastoralists, a well-established ethnographic method called free listing (Borgatti 1999) was used to elicit names of forage plants for livestock production (see Appendix 1 with the ethnobotanical structured questionnaire). Based on this free list approach, other structured questions were asked as part of the whole ethnobotanical survey process in order to ensure proper documentation of answers in a logical manner (see Chapters 4, 5 & 6).

3.3 Broad study methodological framework

As outlined in Section 2.2 above on SES conceptual framework, the investigation of this forage-related LEK among local agro-pastoralists within the West African context primarily link the two key social and ecological variables. The chief rationale for the selection of a wide-ranging study area is also to allow for a trans-national and cross-cultural comparison of LEK and grazing management strategies among local agro-pastoralists living under different environmental conditions and having different ethnic and socio-economic backgrounds. The anthropological influences in the management of natural resources management (including livestock grazing) in the research region have been markedly noticed over the years, since humans continue to extract provisioning ecosystem services from the physical environment for their own survival. This then makes both subsystems of the SES approach to be mutually dependent on each other to be resilient and stable in times of social and natural disturbances of these subsystems (see Fig. 3).

For the social subsystem of the SES research approach used in this study, I employed stratified random sampling to capture vital socio-economic or socio-demographic characteristics of local agro-pastoralists including their ethnic, residential, gender and educational backgrounds as well as their age categories considered in this research (see Chapters 4, 5, 6 for sampling design). Hence, socio-linguistic membership, especially ethnic groups, can influence the manner in which the available forage resources are utilized, and thus this study intends to explore such potential influences on agro-pastoralists' LEK accumulation (Chapter 4), valuation criteria (Chapter 5) and their knowledge and perception of ecological variables such as forage diversity, habitat distribution abundance trends and multiple drivers in the target rural communities (Chapter 6). In choosing three dominant ethnic groups (Dagbani, Gurunsi and Mossi) in the different rural communities with varied aridity conditions, I assumed that the collective experience of a more pronounced climatic aridity along the climate gradient would influence LEK in a consistent way. Historically, these three dominant ethnic groups share a common linguistic family (Gur language), which partly explains why some vernacular names of cited forage plants were quite similar during the field interviews. Broadly, I opted for individual-based observational ethnobotanical surveys but not via focused group or group discussion to understand the independent ethnoecological knowledge of forage resources that the local agro-pastoralists with varied socio-cultural and environmental settings exhibited in a multilevel fashion. I also employed a free list technique (Borgatti 1999) to obtain free list length of edible forage plants cited by local agro-pastoralists as a proxy means of measuring the distribution of forage-related LEK among them (see

Chapter 4 for sampling details). To establish local trust and obtain substantial ethnobotanical information from the local agro-pastoralists in the interview process, I asked informants to provide an unlimited number of natural forage plant species, unlike Ayantundi et al. (2008) who did their ethnobotanical study by giving local informants a few lists of predetermined plant specimens for identification in Niger. Personal observations and ethnobotanical walks were conducted to collect voucher specimens of forage plants that were cited during the interviews (see Chapter 4).

With respect to the ecological component, the ethnobotanical inquiry of this study looks at the forage resource availability and biodiversity metrics, as well as the abiotic climatic aridity variable. Considering the importance of the SES research in developing innovative research methods to operationalize trans-disciplinary investigations (Ostrom 2009), the clarion call for the integration of social and ecological domains by many contemporary researchers is the way to go, reflecting the human-environment relationship. This study employs a multi-pronged approach to understand and harness LEK of forage resources among local agro-pastoralists residing along a steep climatic gradient in the West African Guinean-Sudanian savannas. To triangulate ethnobotanical data gathered from the local informants for the assessment of local valuation criteria of forage resources for livestock grazing, vegetation sampling was done to take inventory of especially woody plants for subsequent comparisons for subsequent determination of their scientific names. In fact elaborate literature on LEK of forage resources in the West African Sudanian savanna ecosystems is very rare. Regarding statistical analysis of the collected data, this study uses a modeling approach to disentangle the fixed and random effects on various components of LEK regarding forage resources rarely done in ethnobotanical studies rather than the use of conventional hypothesis testing. Also, species diversity metrics were estimated for cited forage species by local informants.

3.3.1 Ghana

Geographically, Ghana is situated within latitude 4° 44’N and 11° 11’N and 3° 11’W and 1° 11’E longitude, bordering on the west coast of Africa and has a total land area of about 239,460 km² (Oppong-Anane 2006). The country shares borders with Côte d’Ivoire to the west, Togo to the east, the Gulf of Guinea and the Atlantic Ocean to the south and finally Burkina Faso to the north (see, Figs. 4, 9 and 13, Appendix 2). Based on the population and housing census (PHC), the total population of Ghana stands at about 24,658,823 people, out of which the Northern region had a population of 2,479,461 and the Upper East region had a population of 1,046,545 as in 2010. The latter include 50.4 percent and 51.6 percent of females and males as in 2010 respectively (GSS 2012). The Northern Region of Ghana is dominated by Muslim religion with a population of about 60 percent although the country is largely composed of about 72 percent of Christians (GSS 2012) and a small proportion of traditionalists. The Upper East Region, on the other hand, has a majority of Christians as compared to other religious beliefs. There is a general perception that the northern part of Ghana has higher poverty incidences, food insecurity, interethnic conflicts and economic under-development when contrasted with the southern part of the country (Yaro 2004, Dietz et al. 2013, Wood 2013).

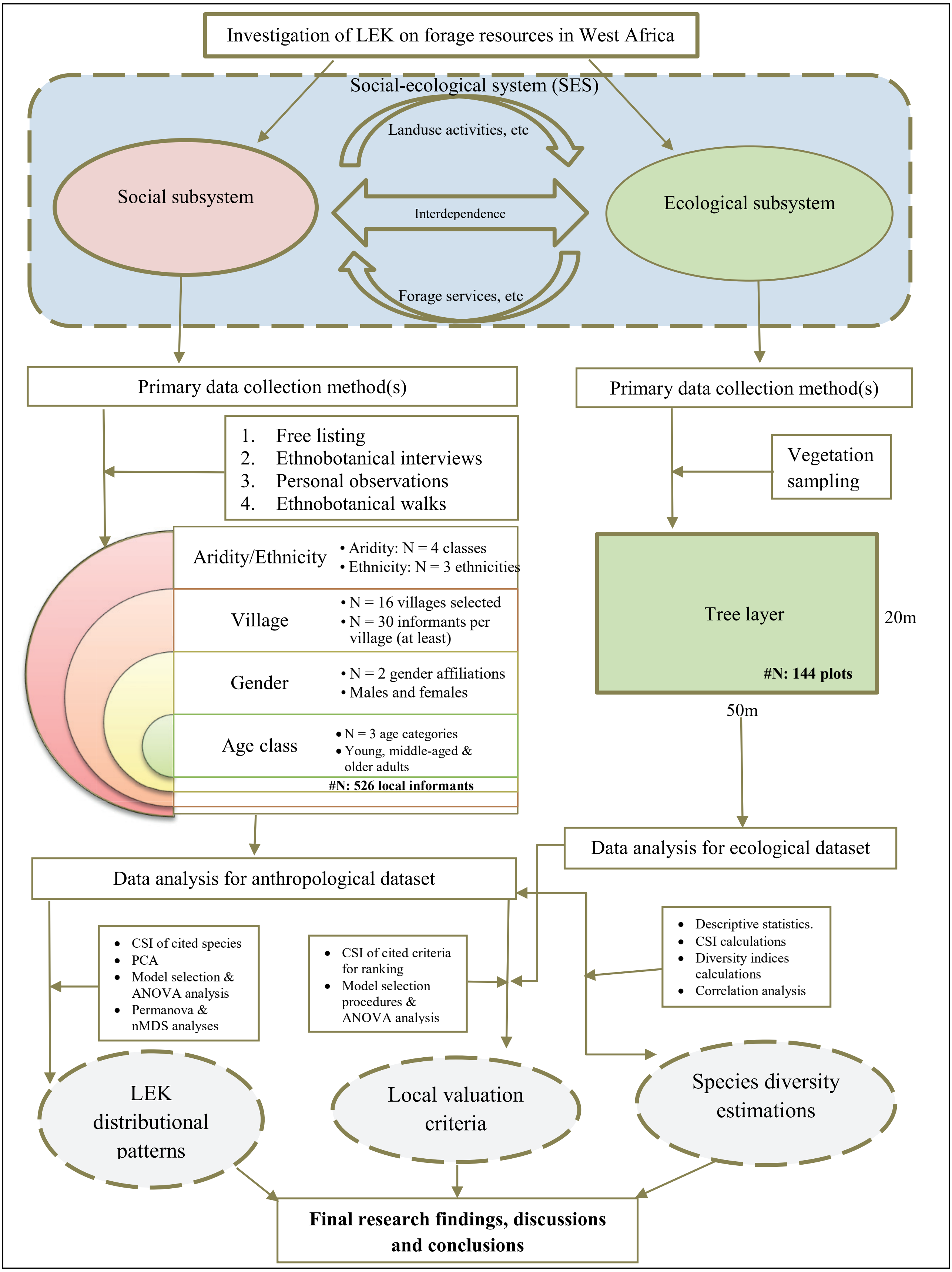
Investigation of LEK on forage resources in West Africa
Social-ecological system (SES)
Landuse activities, etc
Social subsystem
Interdependence
Ecological subsystem
Forage services, etc
Primary data collection method(s)
Primary data collection method(s)
1. Free listing
2. Ethnobotanical interviews
3. Personal observations
4. Ethnobotanical walks
Vegetation sampling
Aridity/Ethnicity
• Aridity: N = 4 classes
• Ethnicity: N = 3 ethnicities
Village
• N = 16 villages selected
• N = 30 informants per village (at least)
Gender
• N = 2 gender affiliations
• Males and females
Age class
• N = 3 age categories
• Young, middle-aged & older adults
#N: 526 local informants
Tree layer
#N: 144 plots
20m
50m
Data analysis for ecological dataset
Data analysis for anthropological dataset
• CSI of cited species
• PCA
• Model selection & ANOVA analysis
• Permanova & nMDS analyses
• CSI of cited criteria for ranking
• Model selection procedures & ANOVA analysis
• Descriptive statistics.
• CSI calculations
• Diversity indices calculations
• Correlation analysis
LEK distributional patterns
Local valuation criteria
Species diversity estimations
Final research findings, discussions and conclusions

Fig. 3: Methodological flowchart of the ethnoecological research carried out in the West African Sudanian Savannas, specifically in northern Ghana and southern-central Burkina Faso.

3.3.2 Burkina Faso

Burkina Faso has an estimated human population of 14,017,000 as at 2006 (INSD 2009). Its total landmass covers an area of about 274,200 km² and lies between 9° and 15.5° N as well as 6° W and 3°E (Waongoa et al. 2015). Further information on the climate, geology and pedology, vegetation, flora and land use practices such as domestic livestock rearing and cultivated crops species for both selected countries in the study area is provided in Subsections 4.3.1, 4.3.2 and 4.3.3. Like Ghana, inhabitants in Burkina Faso do cope with their livelihood challenges.

3.3.3 Selection criteria for villages/locations

To obtain primary data on LEK of forage resources from local agro-pastoralists, I set out to specifically select (i) which villages to conduct my research and (ii) who to interview along a steep climatic aridity gradient (see Fig. 3 above). Firstly, I used a systematic sampling approach to choose suitable villages for subsequent ethnobotanical surveys as the study was meant to include heterogeneous ethnic groups. Among a number of selection criteria used for a suitable village in a decision tree, I started off by considering the following factors for the ethnoecological surveys in order of significance:

- **Topography of landscape**: The immediate environment of the villages should have a visible sloping topography for subsequent plots stratification into lowland, mid-slope and upslope positions via vegetation sampling.
- **Local population**: The target villages should have relatively large populations to be able to identify at least 30 suitable informants from each of them.
- **Ethnicity**: Selected villages and informants should fall within the pre-determined ethnic group of the respective climate zone.
- **Distance between villages (site proximity concerns)**: Sampled villages should be at least 20 km away from one another to avoid possible spatial autocorrelation of data and also to ensure a wide geographical spread of selected villages.

3.3.4 Voucher specimens' collection and preparation

The majority of the local dwellers (about 80 percent) in the sampled rural communities I visited during my ethnobotanical interview sessions had very little or no formal educational training. Thus, the local agro-pastoralists were asked questions in their own local Dagbani, Gurunsi and Mossi dialects (see Appendices 1, 8 and 9). This was made possible via the engagement of experienced local field assistants in all ethnic groups to translate vernacular names of forage species and associated questions into English and vice versa. This was necessary because I did not have previously prepared plant species for the local informants to identify. The collected forage plants (especially wild herbaceous and woody plants) were then in turn herbarized according to standardized procedures such as labeling the specimens with their local name, the date of collection, the habitat/location of collection and the collector's name. The vernacular plant names identified during the ethnobotanical walks were then matched with botanical names for further analysis of forage-related LEK. Research has shown that the vernacular names given by indigenous people (in their own dialects) usually reflect a wide spectrum of vital information on their understanding of such plants (Singh 2008).

3.3.5 Agro-ecological zones

The natural vegetation of Ghana has been clearly distinguished into six agro-ecological zones (AEZ; Oppong-Anane 2006), which are influenced generally by the climate and soil characteristics (see Subsection 4.3.2). They include the evergreen rain forest, deciduous rain forest, transition and coastal savannah zones constituting the southern half of Ghana have a bimodal equatorial rainfall pattern (major and minor growing seasons), while the Guinea and Sudan Savannas make up the northern half of Ghana, where this study was conducted. This two AEZs have mostly a uni-model tropical monsoon (one major growing season). The precipitation and temperature variations are controlled by the movement and interaction of continental and maritime winds (Oppong-Anane 2006, Wood 2013). According to Kagone (2006), Burkina Faso has not yet established an AEZ in the strict meaning of the term. However, Guinko (1984) rather established phytogeographical zones based upon the floristic and climatic characteristics, which take the place of AEZ as in the case of Ghana. The four established zones include the Northern Sahelian, Southern Sahelian, Northern Sudanian and Southern Sudanian zones (Kagone 2006).

This ethnobotanical research was conducted in the latter. The bioclimatic condition of the country suggests that the Sahelian climate is much drier than that of the Sudanian climate close to the border of northern Ghana with a largely Guinean-Sudanian climate type. Generally, the climatic condition of the study area is largely semi-arid in nature.

3.3.6 Geological & pedological settings

Geologically, the southern part of the study area covering particularly northern Ghana is commonly composed of the West African Craton, which stabilized in the early Proterozoic (2000 Ma) during the Eburnean Orogeny (Kesse 1985). This part of the country (Northern, Upper East and Upper West regions) mainly consists of the Voltaian system (Late Proterozoic-Early Paleozoic), Granitoids and small portions of Birimian rocks (Late Paleoproterozoic) close to the border of Burkina Faso (Kesse 1985, Carrier et al. 2008). In the north of the study areas (southern and central parts of Burkina Faso), the geology is dominated by the Precambian rocks of the Guinea Rise, largely migmatites, gneisses and amphibolites (Ferner et al. 2015).

In terms of the pedological setting of the study area, the soils of Ghana are developed from highly weathered parent material (FAO 2005). The alluvial (Fluvisols) and eroded shallow soils (Leptosols) are predominately present in all agro-ecological zones in the country (Oppong-Anane 2006). Specifically, the northern half of Ghana is dominated by Luvisols which have a mixed mineralogy, high nutrient content and good drainage (Bridges 1997). However, a low percentage of organic matter and nitrogen contents are common to the savanna and transition zones (FAO 2005), suggesting most soils in these areas are inherently infertile, or infertile due to human activities (Oppong-Anane 2006). On the other hand, the soil types on the Burkina Faso side of the study area, are mostly leached ferruginous soils, poorly evolved soils of erosion, brown eutrophic soils, vertisols, ferralitic soils, halomorphic soils, hydromorphic soils and raw mineral soils (Kagone 2006). Out of these eight main soil types in Burkina Faso, the mostly leached ferruginous soils and poorly evolved soils of erosion cover more than two thirds of the country (Kagone 2006).

3.3.7 Vegetation, floral, faunal and crops-related species compositions

The dryland vegetation provides important ecosystem services, e.g. forage resources, among others, for livestock production (Baumann 2009). Thus, the vegetation and soil types generally serve as the ecosystem 'memory' (Faber et al. 2005), since ecological information on both past climate conditions and land use practices is virtually stored for use by local land users (Baumann 2009). In terms of domestic faunal species, local agro-pastoralists keep common livestock species such as cattle, goats, sheep (considered in this study) and poultry in both countries. However, pigs are not reared in Muslim-dominated areas except in Christian and traditionalists' households. Some local farmers keep dogs) for night protection and/or for hunting purposes and donkeys (not considered in this research) for carrying water and/or farming in both countries. The cultivation of food and cash crops constitutes one of the main agricultural activities practiced among rural inhabitants in Burkina Faso as well as in Ghana. Local farmers in both countries mostly engage in cultivating cereals (maize, guinea corn, pearl millet, and rice), legumes (groundnuts, normal beans, Bambara beans and soya beans), tubers (yams, cassava and potatoes) and other exotic crop species such as cotton, banana and plantain. It was however observed that tuberous crops such as yams, cassava, banana and plantain species were exclusively planted in Ghana where dry sub-humid and humid weather conditions exist for fertile soils. Cotton, in particular, is cultivated on the Burkina Faso side close to the Ghanaian border.

3.3.8 Land use systems

The chief land use type is agro-pastoralism whereby local people do engage in all forms of cropping systems (monoculture or rotational crop farming) as well as animal husbandry by providing natural grazing pasturage platforms to cope with unpredictable precipitation patterns. Various crop residues are also fed to domestic livestock due to declining quality and quantity of available natural forage resources e.g. grasses (Kagone 2006, Oppong-Anane 2006). Subsistence agriculture is the main employment opportunity for over 80 percent of the economically active population in rural Burkina Faso (Callo-Concha et al. 2012). On the other hand, local farmers in Ghana equally engage in peasant agriculture which employs approximately 60 percent of the labour force in the country (Oppong-Anane 2006). Livestock husbandry (mainly cattle, sheep and goats) constitutes a crucial aspect of the livelihood strategies of rural people living in semi-arid West Africa (Turner et al. 2014). In Ghana and Burkina Faso, almost every household rears a few animals (small ruminants, poultry) for home consumption and as financial capital saving in case of crop failures. Cattle rearing is more or less a preserve for the well-to-do individuals in rural communities. These rural communities do have limited social amenities such as water boreholes, road network, schools and so on.

3.4 Ethnoecological research challenges

A host of practical challenges was encountered in carrying out this ethnoecological research in such a wide study area along a steep climatic gradient. These include the following:

- **Match of vernacular and scientific nomenclature from voucher specimens**: One of the overarching practical challenges faced was the matching of vernacular names of cited forage species during the ethnobotanical interviews and their corresponding scientific nomenclature. It was primarily due to the open-ended (limitless) nature of answers provided by local agro-pastoralists via the free list approach without using pre-identified forage plants during ethnobotanical surveys.
- **Time resource constraint**: The inter- and intra-dialectical differences in vernacular names of forage species cited by selected ethnic groups was particularly time-consuming which then warranted repeated collections and preparation of cited forage specimens.
- **Topographic positions in village landscape**: For vegetation sampling, it was challenging to clearly locate different topographic positions (upland, mid-slope and lowland) in nearby village landscapes suitable for where ethnobotanical interviews were done. This was done to capture more possible forage plants at various locations as was done for covering a wide range of age, ethnic and gender groups in sampled villages.
- **Poor road networks**: Poor feeder road networks connecting the various villages in the study area coupled with inadequate logistics posed a serious challenge for conducting several ethnobotanical surveys in many different locations.

- **Randomization of local informants**: It was sometimes difficult to find suitable local informants especially during the rainy season due to increased farming activities, a multiplicity of household chores for female local informants and cultural limitations for women to talk to strangers in the rural communities visited.

The above mentioned challenges were carefully handled to minimize avoidable sampling errors and finally obtain reliable and consistent quantitative ethnoecological data.

4 Factors influencing local ecological knowledge of forage resources: Ethnobotanical evidence from West Africa's savanna

4.1 Chapter abstract and highlights

Recording local ecological knowledge (LEK) is a useful approach to understanding interactions of the complex social-ecological systems. In spite of the recently growing interest in LEK studies on the effects of climate and land use changes, livestock mobility decisions and other aspects of agro-pastoral systems, LEK on forage plants has still been vastly under-documented in the West African savannas. Using a study area ranging from northern Ghana to central Burkina Faso, we thus aimed at exploring how aridity and socio-demographic factors drive the distributional patterns of forage-related LEK among its holders. With stratified random sampling, we elicited LEK among 450 informants in 15 villages (seven in Ghana and eight in Burkina Faso) via free list tasks coupled with ethnobotanical walks and direct field observations. We performed generalized linear mixed-effects models (aridity- and ethnicity-based models) and robust model selection procedures. Our findings revealed that LEK for woody and herbaceous forage plants was strongly influenced by the ethnicity-based model, while aridity-based model performed better for LEK on overall forage resources and crop-related forage plants. We also found that climatic aridity had a negative effect on forage-related LEK across gender and age groups, while agro- and floristic diversity had a positive effect on the body of LEK. About 135 species belonging to 95 genera and 52 families were cited. Our findings shed more light on how ethnicity and environmental harshness can markedly shape the body of LEK in the face of global climate change. Better understanding of such a place-based knowledge system is relevant for sustainable forage plants utilization and livestock production.

Highlights:

- Aridity and ethnicity are important drivers of LEK and their relative importance depend on the types of forage resources considered.
- Local climatic variability poses a major threat to LEK accumulation and ecosystem services provision (e.g. forage resources).

- Gender-based LEK varies depending on ethnicity, aridity and type of forage resource.
- LEK is unevenly distributed among local resource users.

4.2 Introduction

In the tropics and subtropics, particularly in the West Africa’s savannas, vulnerable resource-poor rural dwellers tend to largely depend upon the provision of natural ecosystem goods and services for their survival (MEA 2005, Rinawati et al. 2013). Forage provision is one of such essential ecosystem services; it supports approximately 50 percent of global livestock production (MEA 2005) and contributes to sustainable livestock production in predominantly mixed crop-livestock rural farming communities. Local ecological knowledge (LEK) is a cumulative body of knowledge gained via practical interrelationships with ecosystems by local resource users over the years (Berkes et al. 2000), and is of considerable value for effective management of ecosystem services (MEA 2005). LEK has been recognized to play a significant role in studies on sustainable forms of rangeland management, yet it suffered little attention from scientists and has been ‘inappropriately dismissed’ in the past decades (MEA 2005). Considering the potential value and contribution of LEK to ecosystem management, holders of LEK could therefore be very good 'objects of study' as their knowledge could be harnessed for supporting sustainable resource management efforts.

Currently, LEK has however received growing levels of international recognition as an alternative source of information (Berkes et al. 2000, Steele and Shackleton 2010). This is evidenced by an avalanche of recent LEK-related studies carried out in different bio-geographical locations around the globe (Bollig and Schulte 1999, Asase and Oteng-Yeboah 2007, Ayantunde et al. 2008, Bekalo et al. 2009, Derbile 2010, Azzurro et al. 2011, Gouwakinnou et al. 2011, Houessou et al. 2012, Kgosikoma et al. 2012, Sop et al. 2012, Linstädter et al. 2013, Albuquerque 2014, Kidane et al. 2014, Ouédraogo et al. 2015, Pulido and Coronel-Ortega 2015, Zizka et al. 2015). LEK is generally considered to be differentially distributed among its holders (Briggs 2005, Ayantunde et al. 2008). There is also ample evidence in literature that LEK is gender- and age-specific (Komwihangilo et al. 2001, Camou-Guerrero et al. 2008), and to vary considerably between ethnic groups even within the same region as documented in Burkina Faso by

Sop et al. (2012). Nevertheless, with changing social, economic and environmental conditions confronting local land users, their LEK is at risk of being lost in the near future (Gaoue and Ticktin 2009, Koohafkan and Cruz 2011, Gomez-Baggethum and Reyes-Garcia 2013). Hence, possible loss of LEK may partly lead to reduction in future coping capabilities of local farmers in the face of adverse climatic changes in rangelands worldwide (Koohafkan and Cruz 2011). It is also believed that, there is a dynamic “shifting baseline syndrome” in the acquisition and distribution of LEK, whereby each generation of local land users may consider as a baseline the abundance and composition of species observed at the beginning of their lives, and use this baseline to evaluate changes along time (Hanazaki et al. 2013).

In spite of this increasing body of evidence for LEK investigations of late, only a very few studies solely focused on LEK on forage/fodder plants (Linstädter et al. 2013, Bahru et al. 2014, Nunes et al. 2015). As far as we know, no adequate rigorous statistical modeling approach has been implemented to quantitatively examine the relative importance of particularly cultural background (ethnicity) and/or environment harshness (aridity) for assessing LEK distributional patterns among its holders in Ghana and Burkina Faso. In this paper, we therefore seek to bridge this knowledge gap. Our overarching research question is ‘How is LEK on forage plants spatially distributed across the three dominant ethnic groups sampled along a steep gradient of climatic aridity?’ In an attempt to find out who knows more forage plants than others among a pool of LEK holders, we aske the following specific questions:

1. What are the kinds of forage species known to local agro-pastoralists?
2. Is it more the ethnicity or aridity or both which affect LEK quality and distribution?
3. Have local respondents the same overall depth in their LEK on forage plants, and how elaborate is their LEK on specific forage types?
4. Do local informants with the same background in gender, age, ethnicity and aridity mention the same forage species, and if not, what explains their dissimilarity?

We hypothesize that (1) local informants tend to cite forage species they are familiar with, (2) the more aridity increases from south to north, the higher the variability and diversity of forage plants would be in space and time, leading to higher LEK among agro-pastoralists, (3) respondents show varying levels of LEK on forage plants, and that (4) men would have higher LEK on forage plants than women, while older adults will have a more profound LEK on forage plants than the middle-aged adults who will in turn have higher LEK than the young adults.

4.3 Materials and methods

4.3.1 Study area within a broad regional context

This research was undertaken in two neighboring West African countries, namely Ghana and Burkina Faso between October to December, 2012 and July to October, 2013. The study area specifically covered a wide stretch from northern Ghana to southern-central Burkina Faso, covering the Guinean and Sudanian savannas (Fig. 4). The area is characterized by a north-south climatic gradient of increasing aridity from the south (Ghana) to north (Burkina Faso) of the study area (Fig. 4). Both countries are not only characterized by roughly similarly open dry savanna vegetation type and unimodal rainfall regime (unimodal rainfall pattern lasting for about six months) but are also rich in ethnic diversity. The common soil types include thoroughly weathered parent materials, with alluvial soils (Fluvisols) and eroded shallow soils (Leptosols) common to all the ecological zones in Ghana (Oppong-Anane 2006) while that of Burkina Faso are mostly leached ferruginous soils, poorly evolved soils of erosion, brown eutrophic soils, vertisols, ferralitic soils, halomorphic soils, hydromorphic soils and raw mineral soils (Kagone 2006).

The characteristically open vegetation cover mostly consists of economically important trees and shrubs such as *Vitallaria paradoxa* (sheanut trees), *Adansonia digitata* (baobab). Cultivation of food and cash crops (sorghum, maize, millet, rice, beans, groundnuts, yams) as well as livestock rearing (mainly cattle, goats, sheep and poultry) are the main agricultural activities among rural inhabitants in both Burkina Faso and Ghana (Dessalegn 2005, Derbile 2010, Callo-Concha et al. 2012). The rationale for the selection of these wide ranging study areas was to allow for a trans-national and cross-cultural comparisons of LEK distribution among local agro-pastoralists living under slightly different environmental conditions, ethnic inclinations and socio-economic backgrounds.

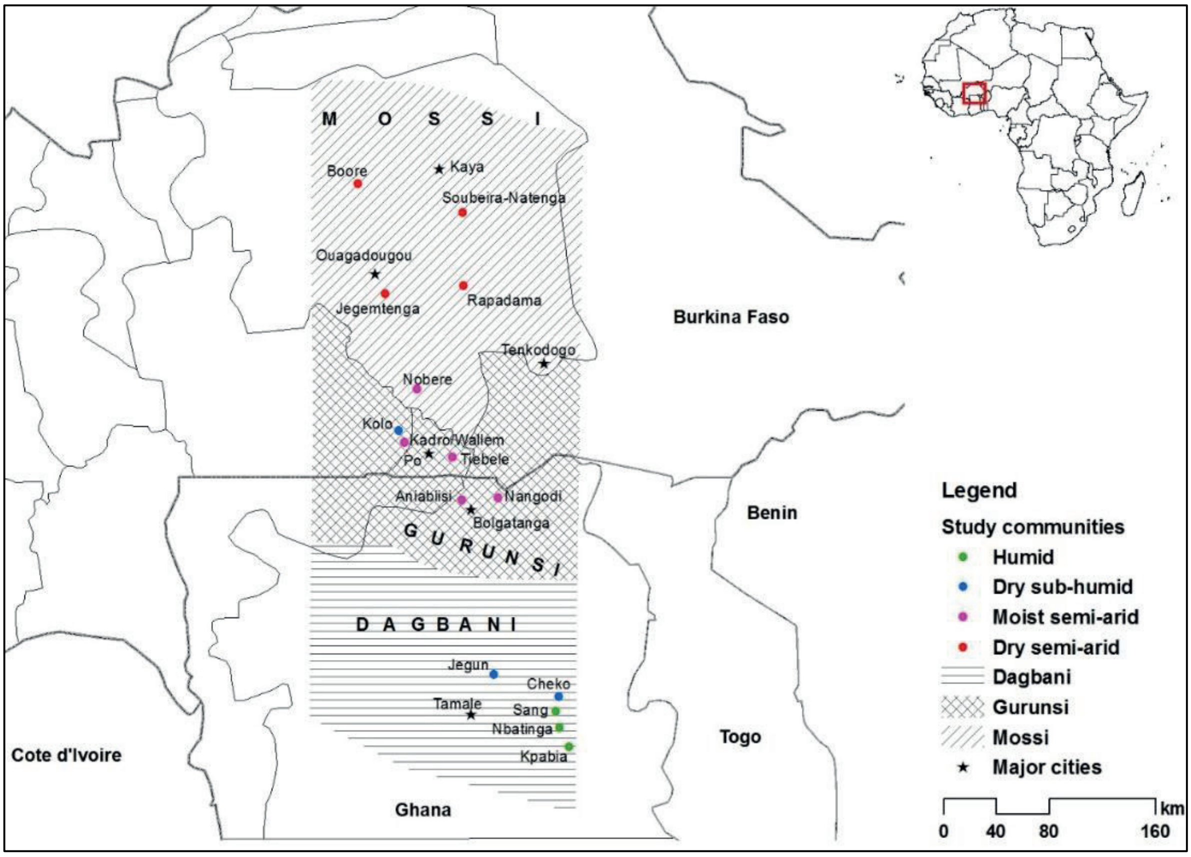

Fig. 4: Study area comprising northern Ghana and south-central Burkina Faso with 15 villages across three major ethnic groups (Dagbani, Gurunsi and Mossi) located along a gradient of climatic aridity. The aridity classes are defined based on aridity indices of villages, following the UNEP aridity classification system and our own subdivision of semi-arid class into moist and dry semi-arid classes. Source: Map by Gerald Forkuor.

4.3.2 Ethnic groups studied

We studied three dominant ethnic groups inhabiting in the study area (Fig. 4). Thus, the Mossi predominantly reside in southern- central Burkina Faso, the Gurunsi living in both sides of the border between Burkina Faso and Ghana, and the Dagbani in northern Ghana. These selected ethnicities share comparable agro-pastoral practices. In the semi-arid West Africa savanna, rural people mostly practice livestock husbandry (mainly cattle, sheep and goats) which constitutes a crucial aspect of their livelihood (Turner et al. 2014), coupled with crop farming activities.

The Mossi mostly inhabit dry semi-arid sites with the harshest environmental conditions in the study area (Fig. 4). They contribute over 50 percent to Burkina Faso's total population (Sop et al. 2012). Traditionally, their rural economy is dominated by subsistence agriculture, with millet, sorghum, maize and cowpea being the main crop plants (Sop et al. 2012).

The Gurunsi ethnic group consists of sub-ethnic groups including Frafras and Nabit in northeastern Ghana only, while Kasenas inhabit both northeastern Ghana and southern Burkina Faso. The Gurunsi group contributes about 5 percent of the total population of Burkina Faso (Kristensen and Balslev 2003) and similar proportion in Ghana. Although these sub-ethnic groups have linguistically distinct dialects yet they have rather similar social, economic and religious practices. The Gurunsi are known to be crop farmers but later adopted agro-pastoralist lifestyle from Mossi and Fulani ethnic groups who migrated to the south to look for better forage resources for their livestock and fertile lands for cultivation (Kristensen and Balslev 2003, Kristensen and Lykke 2003). Within the study area, the Gurunsi mainly inhabit the moist semi-arid environments. Furthermore, the Dagbani ethnic group inhabits both humid and dry sub-humid sites, representing the most humid conditions within the study area. They constitute about 16.5 percent of Ghana's total population (Langer and Ukiwo 2007) and about 60 percent of the population of the Northern Region. Their rural economy is mainly based on agro-pastoralism (involving crop farming and livestock keeping) since the open savanna ecosystem is suitable for such a farming system. With a better rainfall regime than other parts within the study area, crop productivity is quite high among Dagbani farmers. Due to the patriarchal dominance of Dagbani tribe, men own most of the large ruminants especially cattle while their women engage in rearing of goats and sheep, and cultivate mostly 'female crops' such as vegetables, maize, beans, groundnuts, rice, sorghum and potatoes. Women are considered as 'prime producers' especially in the rural economy of northern Ghana (Apusigah 2013). The men rather involve in tuberous crops such as yam and cassava farming due to suitable soils and climatic conditions. However both sexes never rear pigs due to their predominantly Muslim belief system.

4.3.3 Study design and data sampling procedures for ethnic groups, aridity classes, gender affiliation, age groups and residential status of agro-pastoralists

We employed a three-way factorial design of 3 levels of ethnicity x 2 levels of gender x 3 levels of age class (3 x 2 x3). Using stratified random sampling, we selected local agro-pastoralists for the free list tasks. In this article, we used 'local agro-pastoralists', 'local farmers' and 'local informants' interchangeably. The stratified random sampling was more preferred and selected for this study because we wanted to compare possible variations in LEK on forage plants among the sub-groups in our sampling population and also to make the sampling representative, as suggested by Teddlie and Yu (2007).

Ethnicity data collection: The ethnic stratification of local informants was based on the dominant presence of ethnic groups within the study area (Fig. 1) for the free list interviews (see Section 2.4 below for more reading). This was done to disentangle the relative importance of ethnicity on forage-related LEK.

Aridity data collection: To use aridity as a predictor variable, we calculated aridity indices (AI) of all 15 sampled villages using the widely accepted UNEP AI formula (Middelton and Thomas 1997). Thus, AI = P/PET, where P = mean annual precipitation and PET = annual potential evapo-transpiration. The AI data were extracted from a high-resolution global raster climate database from the WorldClim database (http://worldclim.org/version1). We then calculated PET from Thornthwaite's 1948 formula, as explained in Kumar et al. (1987). Based upon the calculated AI per village, we established four aridity classes, namely humid-HUM (>0.65), dry sub-humid-DSH (0.50-0.65), and sub-divided semi-arid (0.20-0.50) into moist semi-arid-MSA (0.39-0.49) and dry semi-arid-DSA (0.20-0.38).

Age-related data collection: Following Eguavoen (2013), we also stratified local informants into young adults (15-35 years), middle-aged adults (36-55 years) and older adults (above 55 years). This was done to see how LEK on forage plants was distributed among local informants under these age categories. We then replicated this random sampling approach in all 15 sampled villages.

Gender affiliation and residential status: The gender stratification was based on the binary male and female affiliations to obtain gendered perspectives of LEK on forage plants. The residential status of local agro-pastoralists hereby refers to native and migrant local agro-pastoralists who still belong to similar, dominant ethnic groups of interest. This variable was recorded but not used for designing this study.

4.3.4 Free list tasks

To assess the levels of agro-pastoralists' LEK on available forage plants for livestock grazing by their small- and large-stock, we applied a well-established ethnographic method known as free listing (Borgatti 1999) used in many recent ethnobotanical studies (Lykke et al. 2004, Quinlan 2005, Duku et al. 2010, Linstädter et al. 2013). Local field assistants were engaged to translate research questions and related follow-ups from English into various local dialects for respondents and vice versa for documentation of their answers. For ethical reasons, local informants were adequately briefed about the essence of the research from the onset of the free list tasks and that their information would be treated confidentially. We did this to get their consent before commencement of the interviews and to build trust with the local folks as well. We also sought permission from local chiefs and opinion leaders in all selected rural communities prior to conducting free list tasks. Before the free list interviews started, we recorded, among others, important local informants' socio-demographic variables in line with our study design as described above.

To capture individual local farmers' LEK on forage plants, we simply asked them to freely list as many as possible plants which cattle, goats and sheep normally feed on. Although the free list approach is a widely used ethnographic tool and appears to be simple, it however provides an incredible understanding into the relevance of LEK and its variation in study communities (Quinlan 2005). This technique makes use of three general assumptions (Romney and D'Andrade 1964, Gatewood 1983, Quinlan 2005) which include: (1) when people free list, they tend to list items in order of familiarity, (2) people who know a lot about a subject list more items than those who know less, and (3) items that most respondents mention indicate locally prominent items. This free list approach is without limitations. Thus, a specific domain can limit respondents' answers and the tendency to reflect mostly respondents' active vocabulary for terms in a particular cultural domain (Quinlan 2005) or interviewees forget to list items (Brewer 2002). We also think that local informants' timidity and unwillingness especially women, at times, to participate in the interview process with a stranger may hamper the delivery of their answers.

Notwithstanding, some of the advantages of free listing include rapid and simple data collection to obtain more samples in less time and easy quantification of free list data (Quinlan 2005). We chose to use the free list approach because its merits seem to outweigh that of its demerits. To help minimize its limitations outlined above, we created a congenial environment during the interview process by adopting friendly attitude and genuine readiness to learn from respondents' answers in an unrestricted manner coupled with probing techniques to get the best out of them. In sum, we covered 450 local agro-pastoralists in 15 villages (seven in northern Ghana and eight in southern-central Burkina Faso), out of which 30 informants were interviewed per village (replicated in five villages)-totaling 150 agro-pastoralists per ethnic group.

4.3.5 Ethnobotanical walks, voucher specimen collection and direct field observations

Ethnobotanical walk sessions were carried out with local experts (mostly older male adults) who exhibited profound LEK on forage plants during free list tasks. Here, ethnobotanical walk refers to taking a guided tour around local immediate surroundings including far bushes usually with at least two persons (e.g. Albuquerque et al., 2014 and Nunes et al., 2015). This "environmental scanning" process was necessary to better understand the local landscape within which these forage plants were present. We prepared voucher specimens of grasses/forbs and trees/shrubby species vernacularly mentioned for subsequent standardized scientific identification with a trained laboratory technician at the Herbarium of the University of Ouagadougou, Burkina Faso. Where necessary, further confirmations were done in the Senckenberg-Museum, University of Frankfurt, Germany.

Also, the scientific names of cited forage species and their authorities were validated using the website of West African plants (http://www.westafricanplants.senckenberg.de/root/index.php). We also cross-checked vernacular names supplied by informants in our study with already published literature, as recommended by Nolan and Robbins (1999). We used Blench (2006) for the Dagbani tribe and (Thiombiano et al. 2012, Zizka et al. 2015) for the Mossi ethnic group to cross-check vernacular names; but no published document was found for Gurunsi vernacular names on plants. Direct field observations on livestock-related issues were made to complement free list tasks. It is asserted that observation of everyday activities may give additional insight into aspects of a culture, including livestock-related activities that may not obviously be visible at first sight (Martin 2004).

4.3.6 Data analysis

To identify factors influencing LEK on forage plants, we employed a step-by-step data analysis approach. In the first step, a full set of predictor variables including ethnicity, gender, age, education, residential status and aridity were subjected to principal component analysis (PCA) to identify possible multicollinearity or collinearity problems. Explanatory variables with higher component loadings retained in the analysis were used for further model selection (as described in third step). To ensure that the predictor variables were non-correlated, we used orthogonal rotation with varimax method. Also, statistical assumptions were explored visually as proposed by Zuur and colleagues (2010). The data exploration was also meant to see what general trends were existing in the dataset and appropriately applied further statistical analyses (Fields 2013).

In the second step, since ethnicity and aridity were found to be collinear, we separately established two candidate global models (ethnicity- and aridity-based models) as also done by Ruppert et al (2015) to predict effects of socio-demographic variables on four response variables (average free list length of all forage plants (For_{total}), herbaceous forage plants-grasses and forbs (For_{herb}), woody forage plants-trees and shrubs (For_{wood}), and crop-related forage plants-fresh crops, crop residues and by-products (For_{crop}) leading to 8 separate models. The final four models were then selected using the Akaike Information Criterion (AIC). The model selection procedure was preferentially selected because it takes care of maximizing the fit as well as the complexity of the model (Johnson and Omland 2004). The generalized linear mixed-effects model (GLMM) was fitted by maximum likelihood (Laplace Approximation). For the ethnicity-based full model, we used ethnicity, gender, age class, educational level and residential status as fixed factors, while in the aridity-based full model, we retained same fixed factors and replaced ethnicity with aridity. The study site (village) was nested within ethnicity or aridity class as a random (intercept) component to correct for site-specific effects for both models. The model selection was done with R package v.3.2.0 (R core team 2015) and all exploratory data analyses including graphics were done using IBM SPSS v. 22.

To find out whether respondents with same aridity and gender had similar LEK on forage plants species, we carried out a two-way non-parametric permutational multivariate analysis of variance (PERMANOVA) in the third step. Sample size was reduced from 450 to 360 informants to obtain a balanced design for the aridity categories. To visualize similarities in patterns of LEK on forage plants, non-metric multidimensional scaling (nMDS) ordination using the Bray-Curtis similarity measure was additionally performed. For the main matrix (respondents x forage species), we transformed free list data with the presence/absence function while the secondary matrix was made of (respondents x informants' socio-demographic characteristics). Each respondent literally represented a plot (as a sample unit). Similarly, Azzurro et al. (2011) used similar multivariate methodological approach in their study on LEK regarding fish diversity in the Mediterranean Sea. Both nMDS and PERMANOVA were carried out using PC-ORD v.5 (McCune and Grace 2002). The calculation of citation frequencies of known forage species was done with freely available Anthropac 1.0 software, suitable for free list datasets (Borgatti 1996, 1999).

4.4 Results and discussion

4.4.1 Forage species richness and their citation frequency among local agro-pastoralists

From the free list tasks conducted, the 450 local agro-pastoralists reported a wide variety of forage species (135), corresponding to 95 genera and 52 families (see Appendix 14 for 19 topmost frequently cited species). This is indicative of the extent to which local agro-pastoralists serve as a repository of knowledge on their local vegetation. Literature revealed that LEK is capable of providing important information on plant species richness, diversity, abundance and rarity (Sop et al. 2012), necessary for not only understanding local vegetation dynamics but also fundamental management strategies for sustainable use and conservation of natural vegetation (Lykke 2000). The most frequently cited forage species points to their nutritive, palatability and cultural values for livestock consumption. Our finding of LEK on For_{wood} with many different woody species cited by local informants as compared to LEK on For_{crop} and For_{herb} supports the ecological apparency hypothesis (Lucena et al. 2012), which states that apparently big and common plants are usually more frequently cited and considered most useful to resource users. The citation of the three different forage types (For_{herb}, For_{wood} and For_{crop}) also signifies the importance of integrated system of ruminant feeding for sustainable livestock production in the midst of unpredictable rainfall patterns over the years in such predominantly semi-arid areas. LEK on For_{crop} was found to be dominant in the free lists given by local agro-pastoralists across all ethnic groups (Appendix 4D). This is an indication of the important role that crops (including residues) play in supplementing the feeding demands of livestock especially in periods of scarcity (dry season). It could also be attributable to the easy recollection of vernacular names for crop plants by local farmers and their familiarity with them for purposes of food as compared to other forage species.

The Poaceae (70 percent of forage species), Fabaceae (8 percent) and Malvaceae (8 percent) were recorded as the most represented forage plant families recorded in this study, which confirmed similar finding in Burkina Faso by Zizka et al. (2015). These plant families have suitable properties (e.g. high palatability, nutritional value, including as forage plants) for livestock consumption and human use (Zizka et al. 2015).

In terms of the differential citation capacity of the informants across selected ethnic groups, Dagbani informants cited more forage species (120) as compared to Gurunsi informants (105) and Mossi informants (89). However, Mossi informants listed more For_{wood} than Gurunsi and Dagbani informants, who in turn named more different For_{wood} than Gurunsi informants. Thus, such different citation frequencies for the three dominant ethnic groups seem to reflect individual cultural preferences in the sense that people with different ethnic backgrounds tend to prioritize differently for a particular use category (as forage plant). This may also be attributable to ease of vernacular names recollection and their familiarity with such forage species.

4.4.2 Relative importance of aridity and ethnicity in predicting LEK on forage plants

Comparing the eight competing candidate models for predicting the body of LEK on forage plants, it was evident that the ethnicity-based model performed better with LEK on For_{herb} ($AIC_{ethnicity}$ 1927.3 vs. $AIC_{aridity}$ 1931.4) and For_{wood} ($AIC_{ethnicity}$ 2127.1 vs. $AIC_{aridity}$ 2133.7) than the aridity-based model. Regarding For_{total} and For_{crop}, the aridity-based model was rather superior to the ethnicity-based model with lower AIC values: For_{total} ($AIC_{ethnicity}$ 2683.5 vs. $AIC_{aridity}$ 2681.2) and For_{crop} ($AIC_{ethnicity}$ 1956.9 vs. $AIC_{aridity}$ 1951.6).

The four final models as reported above were equally plausible since delta AIC values were >2. However, both separate candidate models did have low marginal and conditional R^2 values (see Table 1 beneath). Our finding therefore suggests that it is not only a respondent's environmental setting (aridity at a given site) that determines the extent of LEK on forage plants but also the cultural setting (ethnicity) with respect to the aspect of LEK one is seeking to address. Thus, both factors are important but for certain components of LEK under study and can be misleading to general LEK findings. However, since the aridity-based model outperformed the ethnicity-based model for LEK on For_{total}, which is an embodiment of all four forage plant types cited, one could infer that aridity is more influential in forage-related LEK patterns than ethnicity. Our hypotheses that ethnicity is more important in shaping forage-related LEK than aridity and that harsher environmental conditions coupled with the cultural relevance of livestock-based income would lead to higher LEK score especially on woody forage plants were not fully met.
Better performance of the aridity-based model regarding For_{total} and For_{crop} may be explained by two reasons: (1) people's overall LEK on forage plants tends to be more strongly shaped by the prevailing local environmental conditions than ethnic affiliations and (2) crop production in the West African Sudano-Sahelian zone is rain-fed and therefore very sensitive to variable climatic conditions, as also noted by Mertz et al. (2011). On the other hand, LEK of For_{herb} and For_{wood} were influenced more by ethnicity probably due to the multiple cultural uses of grasses (herbs and forbs) and trees (shrubs), not only for grazing and browsing but also serve as traditional housing materials, for weaving local hats, pestle and mortar production and medicinal purposes, reflecting the cultural identities of local inhabitants.

4.4.3 Effects of climatic and socio-cultural factors on forage-related LEK among agro-pastoralists

The distribution of LEK among its holders is not only usually influenced by several factors including socio-economic variables such as gender, age, and ethnicity (Sop et al. 2012), but also environmental variables such as aridity. We tested the effects of the aforementioned factors on LEK about forage species from various sources, namely crops, herbs and woody plants. Total forage-related LEK (For_{total}) was significantly influenced by the interacting effects of aridity and gender (x^2 = 17.9, P < 0.001) and age class (x^2 = 16.3, P = 0.013) (see Table 1A). These two factors including a correction for village effects explained 35 percent of variance in the data set. Our results indicate that LEK on For_{total} increased with decreasing aridity. In other words, local informants residing in more humid conditions cited higher average number of forage plants than those living in more arid locations. This therefore shows strong evidence for a negative effect of climatic aridity on the body of forage-related LEK, which is in line with a study from Benin (Segnon and Achigan-Dako 2014). Our observation could be explained by the fact that both crop diversity (Traoré et al. 2011) and the diversity of near-natural vegetation typically decreases along climatic aridity gradients (McClean et al. 2005, De Bello et al. 2006), which is apparently reflected in fewer species known by individual land-users.

On the contrary, we rather found that floristic diversity (on the part of forage plants) and agro-diversity have a strong positive effect on forage plants-related LEK, as corroborated by Kristensen and Lykke (2003) in southern Burkina Faso, who stated that informants living in close vicinity to a protected area knew more useful plants than informants living in adjacent, less diverse environments. The positive effects of floristic diversity on the body of LEK might have shadowed the opposite effect of aridity. A plethora of literature argued that arid environments are linked to a strong need to cope with harsh environmental conditions and frequent incidences of forage scarcity threatening or decimating livestock (Newsham and Thomas 2011), leading to a more elaborate LEK than in less harsh environments (Stafford Smith et al. 2009, Linstädter et al. 2013). Our results were not able to confirm these existing findings.

Pairwise comparisons revealed that men and women had similar LEK on For_{total} in a given aridity class (Appendix 4). Thus, both sexes exhibited same level of forage-related LEK when they were interviewed in the same areas, be it in HUM, DSH, MSA or DSA (see Fig. 2A). However, women's LEK in wet environments (HUM and DSH) was significantly higher than in more arid environments (MSA and DSA). Thus, women in wet environments recalled on average (M) = 7.90 forage plants than those who lived in villages with semi-arid conditions. Roughly the same pattern was found for men; where LEK on For_{total} in HUM and DSH areas was higher than those in villages with arid conditions (MSA and DSA; Fig. 5A). For instance, men from HUM environments recalled on average 4.04 and 6.18 forage plants more than those who resided in MSA and DSA respectively, and similar pattern was recorded for men in DSH as compared to MSA and DSA. This is partly attributable to favorable precipitation, soil conditions, high forage species diversity in humid environments as opposed to the arid locations where there are apparently climatic constraints such as scarcity of water and unavailability of forage plants.

Also, pairwise comparisons and visual interpretations of median free list lengths showed a strong, quasi-linear trend for young and middle-aged respondents to name more forage plants in villages with humid conditions (Appendices 4 (A, B, C, D & E); Fig. 6). This trend was not clear for old respondents, who displayed a similar free listing capacity (LEK on For_{total}) across environments with a different climatic aridity. These results are unexpected, as we assumed that an increasing aridity would generally increase the body of forage-related LEK. We also found no support of our expectation that old people would be most knowledgeable; their free listing ability in areas with arid conditions (DSA and MSA) was not different from that of younger informants residing in locations with similar climatic aridity. Surprisingly, it was in fact young adults who had richest forage-related LEK in HUM and DSH environments as compared to older adults residing in DSA environments. In HUM environments, old adults even were the least knowledgeable. Thus, their average free listing capacity was only 19.57 forage plants which was rather lower than the average free listing capacity for middle-aged (21.93 plants), which inturn was less than the young adults (22.03 plants). This finding was unexpected as the latter age group exhibited higher LEK on forage resources than the middle-aged and older adults.

We also found both men and women living in locations with similar aridity conditions (e.g. DSH and HUM versus MSA and DSA); exhibiting similarity in LEK of For_{total}. This could be ascribed to both men and women experiencing similar environmental conditions and interacting with associated locally available forage species. Also, frequent travels by local agro-pastoralists across nearby villages for social events as well as rural-rural migration may facilitate knowledge sharing on forage plants among them.

Similarly, foraged-related LEK among young, middle-aged and older adults was consistently higher for those residing in humid environments than for same age groups in arid locations, suggesting that the closer the similarity in climatic conditions become, the more similar the LEK on For_{total} across age groups since they experience similar environmental conditions and forage resource types (Fig. 6).

Table 1: Results of final GLMMs showing how respondents' LEK on forage plants is shaped by socio-cultural and climatic factors. Only factors and interactions retained in the final models are shown for (A) total forage-related LEK (For_{total}), (B) LEK of crop plants providing forage (For_{crop}), (C) LEK of herbaceous forage plants (For_{herb}), and (D) LEK of woody forage plants (For_{wood}). Note that the random-effect term 'village' (nested in aridity or ethnicity) was retained in all final models. Marginal and conditional R^2 represent proportions of variance explained solely by fixed-effects, or by fixed plus random-effects respectively. Post-hoc results for significant interactions based on Wald chi-square (X^2) tests are provided are also visualized in Figs. 5-7.

A) Response variable: For_{total}	Df	X^2	*P*
(Intercept)	1	4496.6	<0.001***
Aridity	3	41.9	<0.001***
Gender	1	6.09	0.014*
Age class	2	1.50	0.472
Status	1	2.68	0.102
Aridity*Gender	3	17.9	<0.001***
Aridity*Age class	6	16.3	0.013*
Random effect: ~1 | Village/Aridity class			
Marginal R^2	27%		
Conditional R^2	35%		
B) Response variable: For_{crop}	**Df**	**X^2**	***P***
(Intercept)	1	1258.2	<0.001***
Aridity	3	92.1	<0.001***
Gender	1	1.82	0.177
Status	1	2.21	0.137
Aridity*Gender	3	9.70	0.021*
Random effect: ~1 | Village/Aridity class			
Marginal R^2	25%		
Conditional R^2	26%		
C) Response variable: For_{herb}	**Df**	**X^2**	***P***
(Intercept)	1	181.5	<0.001***
Ethnicity	2	1.56	0.458
Gender	1	53.2	0.001***
Ethnicity*Gender	2	11.2	0.004**
Random effect: ~1 | Village/Ethnicity			
Marginal R^2	18%		

Conditional R^2	30%		
D) Response variable: For_{wood}	Df	X^2	*P*
(Intercept)	1	552.3	<0.001***
Ethnicity	2	30.3	<0.001***
Gender	1	16.6	<0.001***
Status	1	4.01	0.045*
Ethnicity*Gender	2	23.3	<0.001***
Random effect: ~1 | Village/Ethnicity			
Marginal R^2	17%		
Conditional R^2	27%		

*<0.05, **<0.01, ***<0.001.

With respect to crop plants used as forage (For_{crop}), only aridity (*P* <0.001) and its interaction with gender (*P* = 0.021) explained differences in LEK among its holders (Table 1B). Moreover, explained variance (conditional R^2) was only 26 percent and thus considerably lower as compared to For_{total}. In all aridity classes, men and women generally recalled similar numbers of crop plants used as forage (Fig. 5B). Mirroring For_{total} results, For_{crop} among women living in HUM and DSH areas was significantly higher than that of women residing in more arid villages (MSA and DSA). Women from a HUM environment recalled on average 5.38 and 5.90 crop plants used as forage more than those living in MSA and DSA areas respectively, while those residing in a DSH villages similarly cited more on average 2.28 and 2.80 crop plants than women in MSA and DSA places respectively.

A roughly similar pattern was observed for men, although men tended to be less knowledgeable, and differences across aridity classes were not as pronounced as for women: Men from a HUM environment recalling on average 7.79 crop plants, while they only recalled 4.68 species (-3.11) in a DSA environment (Fig. 5B). These results are not unexpected since humid conditions tend to favor crop plants availability and women tend to interact more with crop plants for cooking purposes.

Regarding variation in LEK of For_{crop}, men and women exhibited similar distributional patterns across all four aridity classes, suggesting that both sexes had almost equal exposure to and familiarity with these forage-providing crops. The increasing LEK on For_{crop} with decreasing aridity values is explained by better rains in humid locations leading to bumper harvests including crop residues as opposed to arid areas where local farmers usually experience poor crop yields. Local farmers in humid areas may also be more willing to plant or interact with other crop species (being more innovative) which could influence their LEK of For_{crop}. In contrast, people in arid areas may focus on the few crop species which have already been tested on their farms and can cope with such harsh environmental conditions.

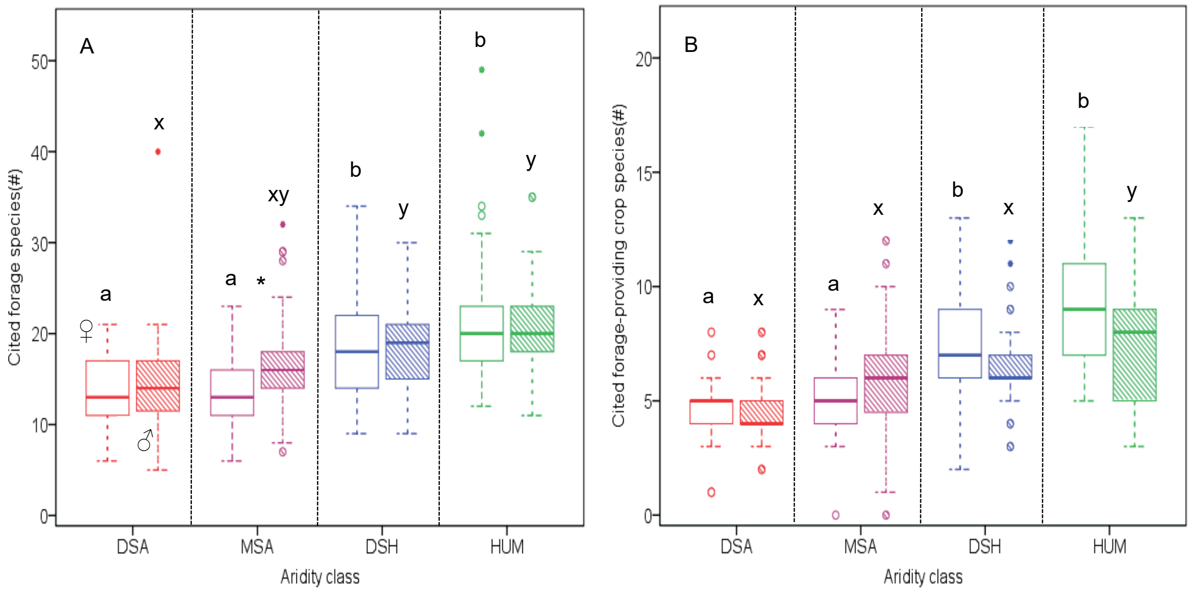

Fig. 5: Boxplots indicating the interacting effect of environmental harshness (aridity class) and gender on (A) respondents' overall knowledge of forage plants (total free list length; For_{total}), and (B) respondents' quantitative knowledge of crop plants providing forage (For_{crop}). The asterisk indicates significant differences (P < 0.05) between gender affiliations within the respective aridity class, while letters give significant differences between gender affiliations across aridity classes. DSA=Dry semi-arid, MSA=Moist semi-arid, DSH=Dry sub-humid and HUM=Humid.

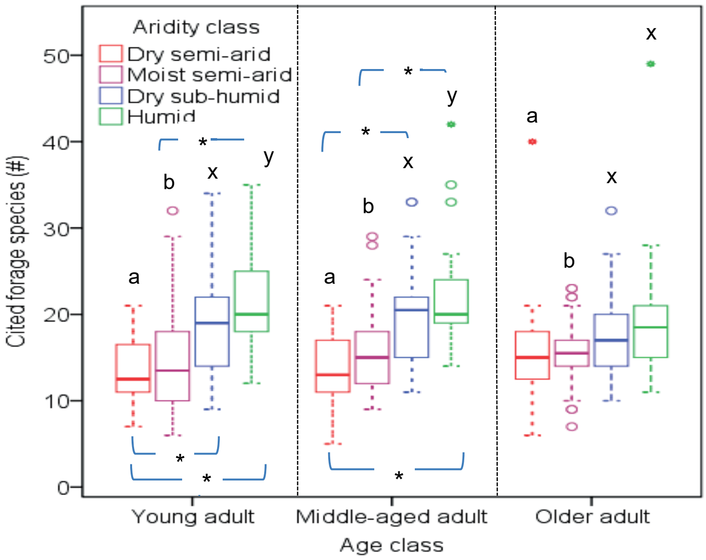

Fig. 6: Interacting effects of environmental harshness (aridity class) and age (age class) on respondents' overall knowledge of forage plants (For_{total}). Asterisks indicate significant differences between aridity classes in the respective age-class (at *P* <0.05), while letter codes represent significant differences across aridity classes for young, middle-aged and old adults, respectively. DSA=Dry semi-arid, MSA=Moist semi-arid, DSH=Dry sub-humid and HUM=Humid.

The interacting effect of ethnicity and gender significantly influence how many For_{herb} informants were able to recall during free list tasks (X^2 = 11.2, p = 0.004, see Table 1C). The amount of variance explained in LEK of For_{herb} was 30 percent. For Dagbani and Gurunsi ethnic groups, men were found to be more knowledgeable in the citation of For_{herb} than women, while both sexes for Mossi ethnic group, on the contrary, had comparable LEK of For_{herb} (Fig. 7A). Our hypothesis that men generally have a richer LEK of forage plants was sustained for For_{herb} cited by Dagbani and Gurunsi informants but surprisingly not for Mossi informants. Post hoc tests revealed that the difference in average free listed For_{herb} for Dagbani men and women (2.80 forage plants) was almost two-fold higher than both sexes for Mossi (0.68) and marginally higher than Gurunsi (1.35) ethnic groups. This result showed the dominance of Dagbani tribe in the citation of For_{herb} in comparison to other selected tribes. Interestingly, while intra-gender variability for men had a similar pattern as that of inter-gender variation for the three ethnic groups, women, on the other hand, exhibited equal knowledge distribution for LEK of For_{herb} among themselves (Fig. 7A). The amount of explained variance (conditional R^2) was only 27 percent.

Gendered LEK of For_{herb} was significantly modulated by the different ethnic groups to which local agro-pastoralists belong. Our alternative hypothesis was upheld for LEK on For_{herb} as men were more profoundly knowledgeable than women for both Dagbani and Gurunsi ethnic groups. This finding corroborates other ethnobotanical studies on forage plants in Northeastern Brazil (Nunes et al. 2015), use of medicinal plants in Benin (Houessou et al. 2012), botanical knowledge on herbaceous species in Niger (Ayantunde et al. 2008) and wild timber species and their uses in Mexico (Estrada-Castillón et al. 2014). Our finding is rather diametrically opposed to Sop et al. (2012) who stated that gender was not a significant determinant in the valuation of woody plants among three different tribes in Burkina Faso. The different gendered LEK on For_{herb} might be ascribed to three possible reasons. Firstly, men are usually regarded as the herdsmen responsible for herding of livestock in many traditional societies. This makes it possible for them to encounter many more For_{herb} than women who largely engage in household chores. This assertion is made in a large body of ethnobotanical literature (Ayantunde et al. 2008, Estrada-Castillón et al. 2014, Nunes et al. 2015). Secondly, large-scale agricultural activities (e.g. clearing ‘virgin’ lands) are usually done by men, exposing them frequently to different types of For_{herb}. Thirdly, men might have more interest in learning about names on For_{herb} than women do in relation to their cultural upbringing. However, similarity in LEK on For_{herb} for both sexes among Mossi informants could either be influenced by equal gender exposure to and interest in For_{herb} based on place-specific social division of labor in gender lines plays no significant role in shaping their level of LEK on For_{herb}. Also, prevailing local environmental conditions may play an indirect role in explaining such variations in LEK on For_{herb}. This is partly evidenced by the fact that Mossi informants who occupied the driest part of our study areas cited fewer number of For_{herb} as compared to Dagbani and Gurunsi groups situated in humid and moist semi-arid areas, making it easier for Mossi men and women to learn vernacular names of For_{herb}. The cultural embedding of LEK on For_{herb} partly explained why the ethnicity-based model marginally out-performed that of the aridity-based.

Furthermore, we also found a significant interacting effect of gender affiliation and ethnic background of local agro-pastoralists' LEK on For_{wood} ($X^2 = 23.3$, $p = <0.001$, Table 1). Follow-up pairwise comparisons and ocular observations of the medians for citation of For_{wood} interestingly revealed a trend which is diametrically opposed to LEK on For_{herb} for same Dagbani ethnic group; in which women rather exhibited a significantly higher LEK of For_{wood} than men (Fig. 7B). Conversely, both sexes exhibited comparable LEK of For_{wood} for Gurunsi and Mossi tribes (Fig. 7B). These results did not support our hypothesis when it came to recalling of For_{wood}. In terms of intra-gender variation in LEK on For_{wood}, Dagbani women, on average, showed significantly higher LEK on For_{wood} than those with Gurunsi (4.76) and Mossi (3.88) ethnic backgrounds. Gurunsi and Mossi women showed similarity in LEK of For_{wood}, although the latter cited slightly higher (but statistically insignificant) than the former (Fig. 7B). It was also revealed that intra-gender variability in LEK of For_{wood} among men was almost comparable across the three dominant ethnic groups (Fig. 7B).

Interestingly, unlike LEK on For_{herb}, women rather cited significantly higher number of For_{wood} than men for the Dagbani ethnic group. Our alternative hypothesis regarding gender effect on forage-related LEK was therefore falsified for LEK on For_{wood}. Unexpectedly, an informant with the highest number of individual forage plants species cited (49) was a Dagbani woman, who was believed to be a 'cowgirl' (a young girl taking care of livestock in the field) in the past. This shows that when women are asked in their area of interest, they are able to perform even much better than men. The strong gender-specific social division of labor in such rural communities coupled with frequent involvement of women in firewood collection, cooking with edible tree leaves, collection of fruits and seeds for consumption, caring for browsers (e.g. goats and sheep) and general home-keeping, go a long way to shape their gendered LEK on For_{wood}. Our finding above supports Estrada-Castillon et al. (2014), who reported that women averagely knew more wild medicinal plants and their uses than men in the Mexican municipality of Rayones.

We also found evidence that both men and women belonging to Gurunsi and Mossi ethnic groups had similar LEK on For_{wood}. This finding suggests that although men and women have got their traditional roles to play, this social division of labor does not have profound influence on their level of LEK on For_{wood}. The main ethnicity effect on LEK of forage plants is coming from the Dagbani ethnic group.

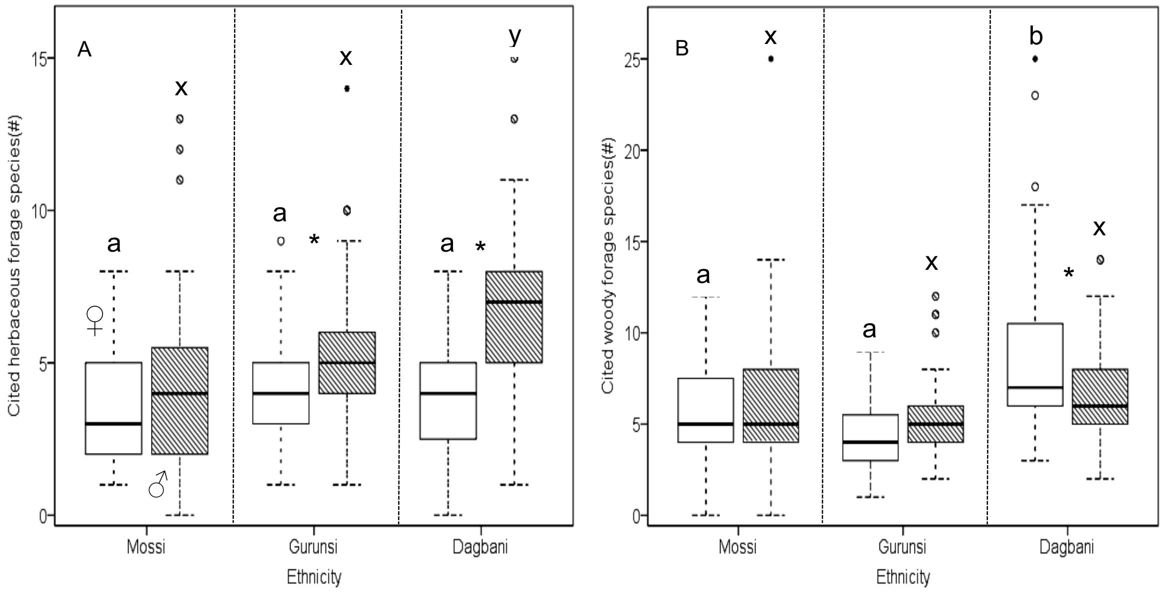

Fig. 7: Interacting effects of gender and cultural setting (ethnicity; with Mossi living in the more arid north, and Dagbani living in the more humid south of the study area) on (A) respondents' quantitative knowledge of herbaceous plants (For_{herb}), and (B) respondents' quantitative knowledge of woody forage plants (For_{wood}). Asterisks indicate differences between males and females within ethnic groups (at $P < 0.05$), while different letters indicate differences between males and females across ethnic groups.

It was also evident that the residential status of local agro-pastoralists was found to have a significant influence on LEK of For_{wood} ($X^2 = 4.01$, p = 0.045, Table 1). For all free list tasks conducted, the natives composed of 86 percent and migrants (14 percent). The former cited a marginally higher number of For_{wood} than the latter (Table 1). This reflects much deep understanding of forage species suitable for livestock production by the natives vis-a-vis the migrants.

Additionally, the PERMANOVA results revealed significant differences for the terms 'aridity class'' and ''gender'' and a significant interaction between these two factors regarding LEK patterns in the citation of forage plants (Table 2). All the four levels of aridity class (with six possible combinations) were significantly different (pairwise comparisons not shown). There was also a significant difference between men and women (Table 2). We thus expected a marked differentiation in among males and females for the four aridity classes. However, the nMDS ordination for LEK on For_{total} largely showed overlapping patterns, except for both sexes in humid areas as compared to those in arid locations (Fig. 8). The PERMANOVA analysis for age class (including interaction with aridity class) using For_{total} (results not shown) was insignificant, suggesting no distinct patterns among age groups in various aridity class. The inferior ethnicity-based model for LEK of For_{total} showed similar PERMANOVA results (not shown).

Table 2: PERMANOVA results for aridity class and gender in explaining patterns of LEK on For_{total}. Df = degrees of freedom, SS = sum of squares, MS = mean sum of squares, Pseudo-F = false F statistic, *P* = PERMANOVA *P* value.

Factor	Df	SS	MS	Pseudo-F	P
Aridity	3	20.2	67.3	44.1	<0.001***
Gender	1	11.1	11.1	72.6	<0.001***
Aridity x Gender	3	11.3	0.38	24.6	<0.001***
Residual	352	53.8	0.15		
Total	359	76.2			

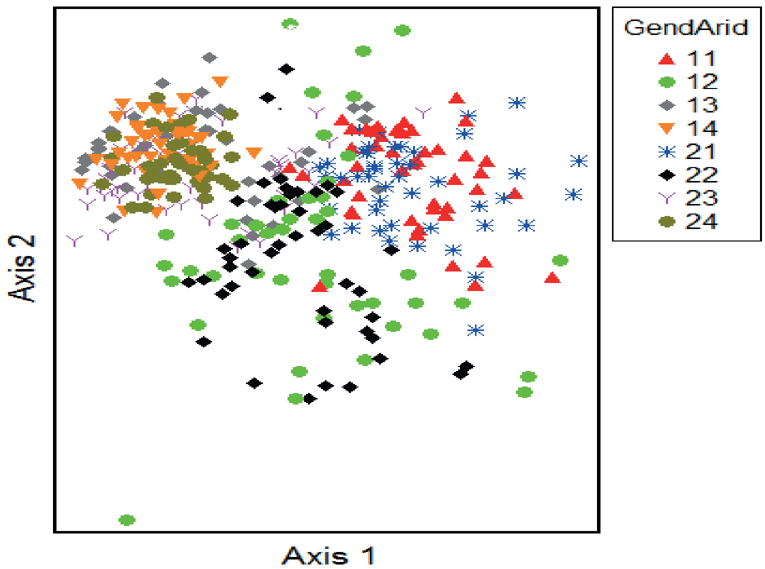

Fig. 8: Two-dimensional non-metric multi-dimensional scaling (nMDS) ordination of sample units in species spaces. Greatest stress reduction was achieved with a 1-dimensional solution, having a stress value of 39.3 percent and a final instability < 0.00284 achieved after 200 iterations. The 11,12,13,14 represent females living in dry semiarid, moist semiarid, dry sub-humid and humid respectively while 21, 22, 23, 24

indicate males resident in aforementioned aridity classes. Axis 1 explained about 43 percent while axis 2 explained about 22 percent, totaling about 65 percent of variance explained.

4.4.4 Local climate change and variability implications for LEK accumulation of forage resources

Some local farmers' perception surveys on climatic variability (Mertz et al. 2009, Mertz et al. 2012) and associated adaptation strategies (Mertz et al. 2011) have been conducted in the Sudano-Sahelian region of West Africa and elsewhere (Smith Jr. et al. 2014). The decline in the average number of particularly For_{herb}, For_{crop} and For_{wood} reported in this study by local informants from more humid to more arid villages is attributable to impact of water scarcity on the productivity of these forage types. Niang et al. (2014) said that climate change does not only have direct impact on crop production by causing varied degree of yield reductions in major cereal crops as a result of water unavailability across Africa but also an indirect negative effect on livestock raising. Rain-fed crop production is said to be more sensitive to climate factors than livestock (Mertz et al. 2011). Thus, the local perception of For_{wood}, For_{herb}, and For_{crop} as crucially important forage sources for livestock production might be a coping strategy, largely informed by prevailing local environmental stress.

Climate change does not only pose potential major threats to global biodiversity but also potentially incapacitates proper local ecosystems functioning, e.g. species regime shift or local extinction (Rinawati et al. 2013). Reduction in biodiversity may eventually lead to reduced adaptive capability of LEK holders and subsequent loss of vital LEK on forage plants in the near future (Koohafkan and Cruz, 2011). This then could make less-resourced rural communities extremely vulnerable to negative impacts of climate change. That being said, local people still thrive to cope with such changing weather conditions and species composition in the face of global climate change. Therefore, by analyzing how local people's socio-demographic characteristics and weather conditions influence the way they behave in the face of adverse environmental conditions such as droughts and poor harvests, is imperative in developing mechanisms for conservation of ecosystem goods and services (including forage plants) for sustainable livestock production.

4.5 Conclusion

Our findings reiterate the point that LEK is unevenly shared among local resource users and can be better understood when it is assessed based upon site- and context-specific factors of interest. Thus, the high variability of LEK on forage plants among local agro-pastoralists in our study is indicative of the intrinsically flexible nature of LEK acquisition and transmission as opposed to well-established western scientific approach. This neither points to inferiority nor superiority of either knowledge system (Briggs 2005), but both can rather play a complementary role. It is also established in this study that levels of LEK distribution considerably vary depending upon various components of LEK in question. Given our findings, LEK is capable of generating a great deal of information on diversity and abundance of forage species necessary for livestock production. With this understanding in mind, policy makers and local project implementers should endeavor to take into account the unique socio-cultural settings of participating local people and communities. Our findings throw more light on how cultural backgrounds and environmental harshness can markedly modulate LEK on overall forage plants in the face of global climate change. Better understanding of such a place-based knowledge system is essential for sustainable forage plants utilization and livestock production to help improve upon the livelihoods of the rural poor. Hence, the findings of this ethnobotanical research could serve as a springboard for interested researchers to investigate various aspects of LEK as well as for local agricultural extension officers and policy implementers in this under-researched study region and beyond to design pro-poor developmental plans with these local beneficiaries in mind.

5 Do local agro-pastoralists have criteria for valuation of forage resources in West African Sudanian savannas? – Using a quantitative ethnoecological approach

5.1 Chapter abstract and highlights

In the face of global environmental change, rural households in the West African savannas are not only confronted with scarcity of water resources but also have to cope with limited forage resources to feed their cattle, goats and sheep in both wet and dry seasons based on their local knowledge. However, there is very little systematic knowledge documentation on local agro-pastoralists' valuation criteria for forage resources in this part of the world. Hence, we aim at examining (1) which forage resources are perceived relevant for different seasonal and livestock types, (2) local agro-pastoralists' explicit valuation criteria for forage resources and their associated salience and (3) how socio-demographic of informants and climatic aridity affect local valuation criteria. To address these aims, we set out to undertake 526 ethnoecological interviews in 16 villages in northern Ghana and southern-central Burkina Faso coupled with vegetation sampling of 144 plots using 20m x 50m per plot. We applied rigorous model selection procedures with generalized linear mixed-effects models and calculation of cognitive salience indices. Our results revealed that the majority of the agro-pastoralists regarded herbaceous forage plants to be very palatable for livestock consumption in the rainy season and for cattle while woody vegetation and crop-related forage plants were rather perceived to be more important in the dry season and for goats and sheep. The findings also indicated that climatic aridity significantly influenced how many forage-related valuation criteria were cited by agro-pastoralists for different seasonal and livestock types. We found that agro-pastoralists did not only judge forage plants based on their availability but also on other criteria such as palatability, stimulation of milk production or their contribution to a healthy growth of livestock. We conclude that understanding local agro-pastoralists' valuation criteria for natural forage resources is crucially important for species conservation and sustainable rural agriculture.

Highlights:

- Herbaceous forage plants are most valuable in the rainy season and for cattle.
- Woody and crop plants are most salient for the dry season, goats and sheep.

- Aridity significantly influenced agro-pastoralists' local valuation criteria in northern Ghana and Southern-central Burkina Faso.
- Healthy growth of livestock was consistently highest underlining reason of ranked forage resources.
- A mixture of varied forage sources is good for different seasons and livestock types.

5.2 Introduction

Drylands constitute approximately 41.3 percent of the terrestrial landmass of our planet (MEA 2005), while 90 percent of whom live in developing countries (Reynolds et al. 2007). These global drylands have expanded in the last six decades and will continue to expand in this 21st century under a warming climate (Feng and Fu 2013). Such expansion of global drylands will negatively affect many people, especially rural farmers (Feng and Fu 2013) and lead to decline in natural forage resources for livestock grazing. The main source of livelihood for about 1.3 billion smallholder farmers worldwide is said to be agriculture, which is particularly susceptible to impacts of climate change (World Bank 2008). Being well-known as the backbone of the West African economy, the agricultural sector employs over 50 percent of the labor force in Ghana (Kolavalli et al. 2012) and about 80 perent of the economically active population in Burkina Faso (Callo-Concha et al. 2012).

The West African Sub-Sahara (WASS) is characterized by a semi-arid climate with a high rainfall variability and regarded as one of the poorest regions in the world (Mertz et al. 2011). Thus, such high degree of inter- and intra-annual rainfall variability in this region not only causes highly variable forage quality and quantity but also seriously limits other ecosystem provisioning services (MEA 2005, Heubes et al. 2011, Jalloh et al. 2012) and therefore aggravates the living conditions of the vulnerable rural poor (Niang et al. 2014). In spite of climate-related risks and human-induced impacts on the rural populations, local farmers persistently cope with such challenges and still forge ahead to meet their daily basic needs of life (Mortimore and Adams 2001). For instance, local pastoralists in the semi-arid Morocco have been reported of using their 'old strategies' to adapt to the new, changing climate (Korbinian et al. 2014) for their survival.

Across semi-arid environments like Ghana and Burkina Faso, several studies have used local ecological knowledge (LEK) approach to investigate savanna trees including their use value and management (Kristensen and Balslev 2003, Lykke et al. 2004, Hansen et al. 2012, Sop et al. 2012, Pouliot and Treue 2013, Zizka et al. 2015) or analyzed pastoral management patterns in the West African regional context (Bassett and Turner 2007, Krohmer 2012).

According to the ecological apparency hypothesis, EAH (Lucena et al. 2007, 2012), the apparent plants are commonly used and highly valued by beneficiary users as compared to the fewer and smaller ones. Literature has also shown that elaborate LEK studies on different forage plants, including their palatability, phenology, life history and availability on local pastures are of crucial importance (Bollig and Schulte 1999, Fernandez-Gimenez 2000, Roba and Oba 2009). Thus, the valuation of forage resources by local land users is a crucially important component of an adaptive natural resource management (Linstädter et al. 2013).

Unfortunately, however, local valuation criteria for available forage resources from agro-pastoralists are still vastly under-documented particularly in the West African Guinean and Sudanian savannas. Moreover, factors which influence local agro-pastoralists' decisions on whether forage resources are good or not for sustainable livestock production still remain elusive. To our knowledge, no such quantitative ethnoecological study has focused on this aspect of LEK in northern Ghana and southern-central Burkina Faso, except this study. In this study, we do not only focus on studying local valuation criteria for herbaceous forage plants (grasses and forbs) but also consider woody and crop-related forage plants used by commonly domesticated livestock, considering these livestock types do have varied feeding preferences. We hypothesize that the local valuation of forage resources is based on several criteria during different seasons (wet and dry) and for different livestock types namely cattle (*Bos taurus* L.), goats (*Capra hircus* L.) and sheep (*Ovis aries* L.). It is estimated that about 25 percent of cattle, 33 percent of sheep and 40 percent of goats are reared among smallholder farmers in the WASS (SWAC/OECD 2008). We also presume that identifying plants or groups of plants that are judged as important by local people can effectively assist the conservation and management of keystone natural forage plants and thus ensure the reproductive success of livestock. The major objectives of this study are:

1. To find out forage types crucially relevant for livestock consumption in different seasonal contexts.
2. To identify local criteria for valuation of forage plants among agro-pastoralists and to assess their salience for livestock production.
3. To investigate how the socio-demographic and climatic aridity variables affect the citation of local valuation criteria for forage resources.

5.3 Materials and methods

5.3.1 Environmental setting

The ethnoecological surveys among local agro-pastoralists encompassed northern Ghana and southern-central Burkina Faso. This wider study area covers about 530 x 200km^2 north-south extension (Ferner et al. 2015), representing a steep climatic aridity gradient within the West Africa's Guinean and Sudanian savannas (Fig. 9). Thus, the southern part of the study area covers the Ghana side with dry sub-humid conditions to humid while the northern portion of it encompasses Burkina Faso with harsher, drier semi-arid weather conditions. The intermediate aridity class (moist semi-arid) lies in-between, making four climatic aridity classes delineated for this study.

The climate of the study area is characterized by a unimodal rainy season starting from April to October in the south and around May to August in the north. The mean annual precipitation (MAP) in the southernmost part ranges between 800mm and 1500mm (Oppong-Anane 2006). The MAP for the intermediate climatic zone declines to about 700mm to 1200mm (Blench 1999) and then further falls to about 750mm to 950mm in the northern part of the study area in Burkina Faso (Nacoulma et al. 2011). Farming activities are predominantly undertaken by local agro-pastoralists in the rainy season. The harmattan period (dry season) begins in December and ends in March in both countries. The vegetation of the study area is characterized by open dry savanna type. Outside protected areas, the sparse tree layer mostly consists of economically important trees and shrubs such as the sheanut tree, *Vitellaria paradoxa,* or the baobab, *Adansonia digitata* (Traoré et al. 2013, Ouédraogo et al. 2015). Some tree species which contribute to ruminant nutrition include *Afzelia africana, Pterocarpus erinaceus* and *Piliostigma sp* for cattle in particular while *Balanites aegyptiaca, Ziziphus mauritiana* and *Acacia sp* are primarily fed on by small ruminants (Zampaligré et al. 2013). The grass layer in the northern Sudanian pastures in Burkina Faso is dominated by *Andropogon pseudapricus, Loudetia togoensis, Aristida kerstingii, Dactyloctenium aegyptium* and *Digitaria horizontalis* (Kagone 2006, Zampaligré et al. 2013). The southern Sudanian zone is similarly dominated by *Andropogon sp* while *Hyparrhenia* and *Schizachyrium* sp are co-dominants in both northern Ghana and southern Burkina Faso (Kagone 2006, Oppong-Anane 2006). The singular distinguishing vegetation feature is that, the northern Sudanian zone constitutes mostly patchy vegetation cover and many bare grounds (Zampaligré et al. 2013) and fewer tree species, while the southern Sudanian zone has a continuous herbaceous cover interspersed with fire-resistant and broad-leaved trees (Oppong-Anane 2006). We used varying degrees of aridity conditions in the study area to better understand how it influenced the citation of valuation criteria among local agro-pastoralists in a consistent manner.

5.3.2 Cultural setting

Diverse ethnic groups inhabiting Ghana and Burkina Faso. However, for this study, we largely focused on three dominant ethnic groups living along the north-south climatic aridity gradient (Fig. 9), i.e. the Mossi in central and southern Burkina Faso, the Gurunsi living on both sides of the border between Burkina Faso and Ghana, and the Dagbani in northern Ghana (Chapter 4). These ethnicities share comparable agro-pastoral practices. Livestock husbandry (mainly cattle, sheep and goats) constitutes a crucial aspect of the livelihood strategies of people living in rural semi-arid West Africa (Turner et al. 2014). The Dagbani, Mossi, and Gurunsi agro-pastoralists engage in cropping systems (monoculture or rotational crop farming) as well as in animal husbandry by providing natural grazing pasturage platforms to their livestock so as to cope with the unpredictable precipitation patterns. Various crop residues are also considered to be vitally important and fed to domestic livestock due to declining quality and quantity of available natural forage resources such as herbaceous plants (Kagone 2006, Oppong-Anane 2006).

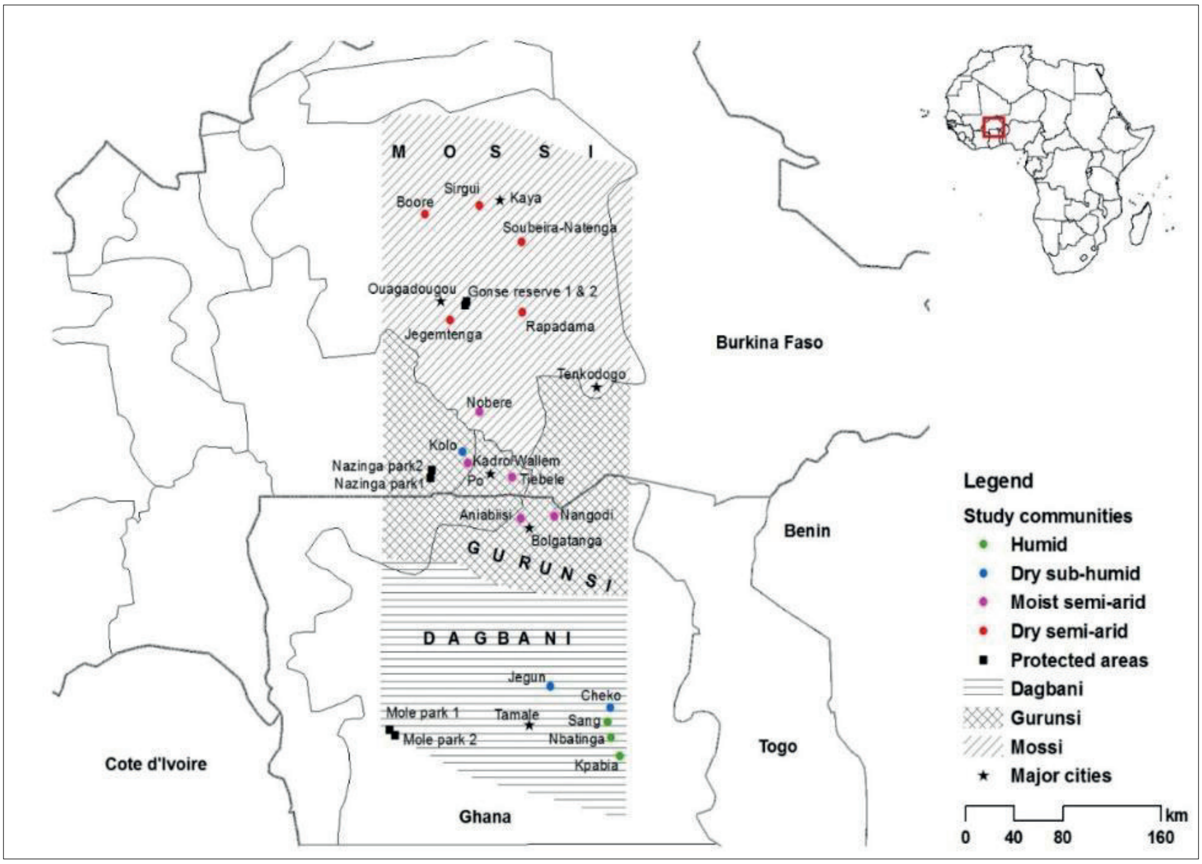

Fig. 9: Map depicting the three major ethnic groups in 16 rural communities and the climatic aridity classes located within northern Ghana and southern-central Burkina Faso. Source: Map by Gerald Forkuor.

5.3.3 Study design and sampling approach

For the study design, we adopted a three-way factorial design of 3 levels of ethnicity x 2 levels of gender x 3 levels of age class (3 x 2 x 3), as explained in Chapter 4 above. To capture information on local valuation criteria for forage plants from local agro-pastoralists, we also adopted a stratified random sampling based on important socio-demographic characteristics such as ethnicity, age and gender (Chapter 4). This stratification of informants was replicated at each study site (village). The stratified random sampling was applied to collect representative data in the sampling population across ethnic groups, age classes, and gender affiliation. We randomly selected five study villages per ethnic group and further stratified per village by gender and age groups (Fig. 9). We adopted age class definitions from previous studies in West Africa's Sudanian savannas (Kristensen and Balslev 2003, Eguavoen 2013), and distinguished informants into young (15-35 years), middle-aged (36-55 years) and old (>55 years) adults. The ethnic and gender stratifications were also done based on dominant ethnic groups (e.g. Dagbani, Gurunsi and Mossi) and males and females respectively (Chapter 4). Thus, the villages were generally nested within ethnic groups or aridity classes during the sampling process (Fig. 9).

Apart from the three main afore-mentioned variables, we also recorded the interviewees' residential status and educational backgrounds. The majority (over 85 perent) of the informants in the study area are native residents (Chapter 4) and many of them are either illiterates or have only basic education. The native residents are those born and still living in the study villages or while migrant settlers are those who have moved from other villages and settled in the study villages for a number of years. The migrants and people with secondary and tertiary education are few in the research area. In sum, we covered 526 informants in 16 villages (seven in northern Ghana and nine in southern-central Burkina Faso), out of which at least 30 informants were interviewed per village (Appendix 2). This was done to disentangle the relative importance of these socio-demographic for valuation criteria among local agro-pastoralists in a consistent manner.

5.3.4 Ethnoecological interviews

Prior to the commencement of the face-to-face interviews, the structured questionnaires were pre-tested with two informants and fine-tuned so as to avoid too late questionnaire changes and to ensure easy understanding of our questions (Chapter 4). Considering the wide geographical spread and dialectical differences within the study area (see Fig. 9), we had to engage local field assistants from the three pre-determined ethnic groups (Dagbani, Gurunsi and Mossi) to help translate research questions from English into respective local dialects to local informants. The respondents' answers were then documented in English. Knowing that different local assistants may affect delivery of answers from local farmers, we minimized their individual influences on answers given. Firstly, the first author adequately trained them, pre-tested questions and was personally present during interviews to ensure harmonization of the structured questions and associated answers given by local informants for documentation. Secondly, the different interpreters' effects on answers were also reduced to the barest minimum by simplifying questions which needed straightforward answers. Hence, we did not model the effects of local informants on the ethnobotanical information gathered since we consciously minimized such possible sampling error source. To gain local informants trust and their permission for the ethnobotanical surveys, we firstly went to the traditional chiefs and local authorities to ask for their permission and secondly proceeded to engage local informants whose consents were also sought prior to commencements of the individual-based interviews (Chapter 4).

To better understand informants' local valuation criteria for forage plants on pastures, we asked open-ended questions (free lists) in the same manner during the ethnobotanical interviews. This provided local informants equal opportunity to answer a similar set of questions for subsequent comparison of responses and allowing them to express their knowledge and understanding on forage resource utilization in their own terms. This was similarly done by Bryman (2004) and Kgosikoma et al. (2012).

Following the free list tasks described in Chapter 4, local informants were asked to explicitly rank five fodder plants or crop residues from their free lists by starting from the most important to the least important fodder plants or crop residues for their livestock (cattle, goats and sheep). With respect to the seasonally variable importance of the free listed forage plants, we also explicitly asked local agro-pastoralists to separately cite and rank five of them particularly suitable for the dry season and the rainy season irrespective of livestock type. Regarding the local agro-pastoralists' perceptions on grazing value (palatability ranking) of available forage plants, we similarly asked them to provide and rank five fodder plants or crop residues for each category of livestock. This was done because domestic ruminants have specific feeding preferences with regard to available forage plants. In addition, interviewees were also asked to list local plant species which are totally refused by their livestock. To better understand and appreciate why local informants explicitly ranked forage plants in terms of varied seasonal regimes and livestock-specific preferences, we further asked local respondents to provide their own ranking criteria to allow for further content analysis of their responses (see Appendix 1).

5.3.5 Climate data collection

The aridity stratification was done to determine whether climatic conditions did have a substantial effect on local forage valuation criteria provided by agro-pastoralists. As done described in Chapter 4, we calculated a climatic aridity value for each village using the UNEP aridity index, AI (Middelton and Thomas 1997). Thus, AI = P/PET, where P = mean annual precipitation and PET = annual potential evapotranspiration. AI data were extracted from a high-resolution global raster climate database (http://www.cgiar-csi.org/data/global-aridity-and-pet-database); which were modeled at 30 arc seconds (~1km at the equator) based on data available from the WorldClim database (http://worldclim.org/version1).

5.3.6 Vegetation sampling strategy

We firstly set out to specifically select sample plots near to villages where the ethnobotanical interviews were conducted. To obtain ecological data on the tree layer, a standard Whittaker plot size of 20m x 50m (Whittaker 1977) was used. We then placed the Whittaker plots using different topographic gradient (upland, mid-slope, and lowland slopes) to maximize the homogeneity of the vegetation composition within our research area. We placed three Whittaker plots per each slope position, totally nine plots per village. The relatively large plot size was chosen to take account of the patchy distribution of trees and shrubs and to capture most forage species at the sites.

For each Whittaker plot, a complete census of trees and shrubs was done and all the tree/shrubby species were counted, identified and recorded. Thus, the stratified vegetation sample plots were located in proximity to villages (plots not further than 10km from villages) in which the predetermined dominant ethnic groups lived with the aim to avoid spatial autocorrelation. We then replicated the sampling strategy in all sixteen villages sampled, totaling 144 plots. This made it possible to subsequently match ethnobotanical and ecological datasets for better understanding the available forage resources utilization by local.

5.3.7 Voucher specimen preparation

Following the ethnobotanical interviews, we made substantial efforts to search and collect the cited forage plant species with the involvement of at least two knowledgeable local farmers from selected rural communities via ethnobotanical walks coupled with participant observation sessions (Nunes et al. 2015). This was necessary since we did not have already prepared plant species to let local informants identify them. The collected forage plants (especially wild herbaceous and woody plants) were then herbarized according to standardized procedures such as labeling the specimens with a local name, date of collection, habitat/location of collection and collector's name. The taxonomic nomenclature of the herbarized forage plants was subsequently done at the University of Ouagadougou, Burkina Faso via assistance from a well-trained technician and confirmed in the Senkenberg Institute in Germany. However, forage plant species (herbaceous or woody) which were already identified with a high degree of certainty on the field were not herbarized (see Chapter 4).

The taxonomic nomenclature of forage plants follows The Plant List (2013). As recommended by Nolan and Robbins (1999), we cross-checked vernacular names obtained from the Mossi, Gurunsi and Dagbani with already published vernaculars (e.g. Kristensen and Balslev 2003, Blench 2006, Belem et al. 2007, Thiombiano et al. 2012, Zizka et al. 2015). The vernacular names given by indigenous people (in their own dialects) usually, reflect a wide spectrum of vital information on their understanding of such plants (Singh 2008). However, not all cited species were herbarized due to two reasons: (i) unavailability of cited forage species at the time of field research and were unknown scientifically (see Appendix 16) and (ii) taxonomic names were already known by the researchers especially crop plants and common food or economically important trees.

5.3.8 Data analysis

Reconciliation of vernacular and scientific names of forage species (Linstädter et al. 2013) was necessary because no scientifically pre-identified specimens of forage plants were used for the free list tasks. Thus, vernacular plant names given by local informants during the ethnobotanical interviews were subsequently matched to taxonomic names of such forage plants to establish their identities scientifically.

Also, we conducted descriptive statistics on the occurrence of groups of forage resources (e.g. trees/shrubs, herbaceous grasses/forbs and crop-related forage plants) as explicitly ranked by local agro-pastoralists during the ethnobotanical interviews. Thus, the suitability of cited forage species were ranked on the basis of seasonal differences (rainy and dry seasons) and livestock-specific preferences (cattle, goats, sheep). This was done with the aim to determine which forage resource types were mostly considered as most suitable or palatable for varied seasonal and livestock types in the research area.

To quantitatively examine the salience of the explicitly ranked forage species in different local settings, we applied the cognitive salience index, CSI (Sutrop 2001), which is based upon the frequency of forage species cited (F) and the mean position (mP) on free lists and sample size (N) for informants. Thus, CSI = F/[N*mP]. The higher the CSI the higher the cultural importance (salience) of a forage species to the local informants (Thompson and Juan 2006). The CSI ranges from zero to one. The CSI values were calculated for each seasonal and livestock type considered in this study. Before detailed CSI analyses were carried out, we excluded forage species with no scientific information for only ethnobotanical-based data (CSI_{ethno}) in order to ensure clarity in the explanation of the forage species salience results (also see Linstädter et al. 2013). For all CSI-related analyses in this paper, we employed the ANTHROPAC 1.0 (Borgatti 1996) statistical software.

Additionally, for the plot-based data or the ecological-based data (CSI_{plot}) collected at various topographic positions in nearby local landscapes, where ethnobotanical interviews were done, we equated forage species as they were recorded per plot as a free list of forage species provided by an individual respondent so as to apply the CSI formula above, as done by Linstädter et al. (2013). Thus, for the CSI_{plot} calculations on encountered forage species, we quantified salience of a forage species as follows: F = the frequency of forage woody species as recorded on all sampled plots, mP = the mean position of recorded forage species as encountered on the plots and N = the total number of plots sampled in all study sites, be it forage or non-forage species on the plots. With this statistical approach, we were able to later link CSI_{ethno} and CSI_{plot} in order to establish any point of convergence with respect to forage plants availability, frequency, abundance and salience. We only focused on woody vegetation on the Whittaker plots (20m x 50m) and left out also sampling the herbaceous layer on same plots for practical reasons.

In a similar vein, we treated the ‘why’ answers as free listed items and calculated the CSI values (as stated above) for valuation criteria for cited forage resources mentioned by local agro-pastoralists for livestock production and management, since they were asked to cite, as many as possible, their local valuation criteria for available forage resources.

This innovative statistical approach provides information to quantitatively assess the salience of such valuation criteria or collective judgment of locally available forage plants for their livestock consumption and growth. In analogy to the CSI_{ethno} described above, F = the number of times a particular reason (valuation criteria) was mentioned by an informant, mP = the mean position of a given reason by an informant and N = the total number of agro-pastoralists interviewed in the study region.

Furthermore, to examine the effects of socio-cultural and climatic variables on the citation of explicit valuation criteria of forage resources by local agro-pastoralists, we performed a series of generalized linear mixed-effects models (GLMM) with a Poisson error distribution and a (log) likelihood-based model selection procedure (Zuur 2009, Naah and Guuroh 2016), eliminating non-significant effect or interaction-terms (Ruppert et al. 2015). Thus, we treated the number of different kinds of valuation criteria for rainy season (Cri_{RS}), dry season (Cri_{DS}), cattle (Cri_{cattle}), goats (Cri_{goats}) and sheep (Cri_{sheep}) cited by the local informants as count response variables, while the socio-cultural and environmental settings as predictor variables (ethnicity, aridity class, age class, gender, educational level and residential status), representing the fixed-effect terms. It is important to note that age class and educational level were modeled as ordered factors while ethnicity, aridity class, gender and residential status were used as just factors in the model selection process. Also, we used aridity class as a categorical variable instead of it as a continuous variables in the model selection process because of easy comparison of such results to that of ethnic group as a categorical variable. Moreover, in modeling aridity class as a continuous variable, the results were not significantly different from that of the aridity class.

From our correlation-matrix obtained using principal components analysis (PCA) analysis on the predictor variables considered for this study with varimax rotation (see Appendix 7), the ethnicity and climatic aridity variables were found to be collinear. We then established two separate initial global models (ethnicity-based and aridity-based models), which differ in terms of inclusion of either of these terms, for each Cri_{RS}, Cri_{DS}, Cri_{cattle}, Cri_{goats} and Cri_{sheep}, totaling ten competing models. This was done to assess the relative importance of ethnicity and aridity variables in determining the valuation of forage resources by local agro-pastoralists.

Since we implemented a nested design in our stratified study, whereby villages/sites were nested within either ethnic groups or aridity classes, we used (1|Village/aridity class or ethnic group) as our random (intercept) term. This was done to account for potential site-specific differences (Ruppert et al. 2015). This then means that p- values in our results only reflect the main effects or interacting effects of the fixed-terms but not taking into account the possible effect of site/village on differences in the local valuation criteria for forage resources in the GLMM approach used. For the final models in all cases, we evaluated them based on their respective Akaike Information Criterion (AIC) values. We then selected the most parsimonious model as the final model, following the principle of parsimony (Crawley 2002) and performed further analyses. The finals models were subsequently analyzed by using ANOVAs (Type III) and Turkey contrasts to determine multiple comparisons of means. The Marginal, R_m^2 (variance explained by only the fixed terms) and Conditional, R_C^2 (variance explained by both fixed- and random terms) in the responses were calculated. Statistical assumptions were graphically checked by plotting residuals to check normality of errors and homogeneity of variance (Zuur et al. 2010). In our data analysis, we did not encounter over-dispersion problem (where the variance is greater than the mean). The model selection procedures, ANOVAs analysis and R^2 were performed with the Ime4 and $R^2_{GLMM\ (best)}$ packages in R statistical software v.3.2.0 (R core team 2015), while the exploratory analyses were carried out with IBM SPSS version 23 (Fields 2013, Chapter 4).

5.4 Results and discussion

5.4.1 Seasonal and livestock-specific rankings and salience of forage species among local agro-pastoralists

Our findings revealed that 73 percent of the local agro-pastoralists perceived herbaceous plants (grasses and forbs) to be most palatable/suitable for feeding domestic livestock in the rainy season as compared to 27 percent who regarded crops (fresh crops/crop residues) and woody vegetation (trees and shrubs leaves) as most suitable for their livestock in the same season (Fig. 10A). This may be explained by the fact that grasses and forbs are fresher, more nutritious and highly digestible at their early phenological growth stage for livestock consumption in the rainy season. It may also be due to the herbaceous plants being considered as primary food sources for livestock consumption as well as being more abundant forage plants. Thus, there may be no urgent need for animals themselves or livestock owners to look for supplementary feeds such as crop-related forage and leaves of trees and shrubs in this season, suggesting that savanna grasslands are very important for livestock during the rainy season.

Nonetheless for the dry season, approximately 57 percent and 33 percent of local agro-pastoralists highly ranked crops and woody vegetation respectively (compared to 10 for the herbaceous forage plants; Fig. 10B). This may be largely attributable to scarcity or unavailability of good herbaceous forage plants, on the one hand, and tree leaves and crop residues are readily available in the harsher dry season on the other hand. A similar study done in the semi-arid region of northwestern Brazil by Nunes et al. (2015) also reported that informants cited more herbaceous forage species for the rainy season than for the dry season while vice versa was true for the citation of woody forage species by informants, indicating how climatic factors modulate forage quality and quantity. Duku et al. (2010) stated that smallholder farmers ranked their feed sources for small ruminants based on a multiplicity of reasons such as their availability palatability, proximity, abundance, reliability and health risks in the transitional zone of Ghana. However, this study and others failed to quantify the salience of valuation criteria of locally available forage species. We also calculated the cultural importance or salience of reasons provided by local agro-pastoralists for the explicitly ranked forage plants in this study as discussed in Section 3.2 beneath for more details.

Comparing only the preferential ranking of herbaceous forage plants for domestic livestock across different seasons, we found a very sharp decline from the wet season to the dry season. However, forage crops and woody vegetation increased strongly when comparing both seasons across forage types (Figs. 10A and 10B). This reflects the deep understanding and perception of local people on the dynamics of forage value which enable them to provide alternative feeding materials for their livestock in the face variable precipitation patterns. The results also suggest that crop residues are twice preferred over woody vegetation in the lean (dry) season. As indicated by Waziri et al. (2013), having knowledge in various constituents of livestock feed is pivotal to production and productivity. About 60 percent of livestock feeds that are provided by rural population come from crops and crop residues (J. B. Walier, Head of Crop Division, MOFA, Bolgatanga-Personal communication).

Regarding livestock-specific preferences, our results revealed that the preferential rankings for cited forage resource types by local agro-pastoralists were different for targeted livestock types irrespective of the seasonal type. Local agro-pastoralists reported that cattle liked herbaceous forage plants more than goats and sheep (Fig. 10C). Conversely, goats and sheep liked crop-related forage plants more than cattle (Figs. 10D and 10E). Similarly, this is true for woody vegetation. Goats and sheep tend to tree and shrub leaves as good feed sources more than cattle (Figs. 10D and 10E). These findings do support existing scientific literature (Guevara et al. 2008) in that, cattle are mainly described as grazers, goats are generally browsers and sheep are considered as intermediate feeders. The different preferences of these commonly raised livestock types for herbaceous composition, woody vegetation and crop-related forage plants can be used to increase forage utilization and efficiency, suggesting the importance of integrated feeding mechanism usually employed by local land users to be resilient in times of extreme weather conditions for sustainable livestock production and management.

In terms of individual forage species ranked across all climatic aridity classes established in this study, *Pennisetum pedicellatum* Trin was adjudged the most salient herbaceous species with cognitive salience indices (CSIs) of 0.41 and 0.30 for the rainy season and cattle respectively (Figs. 11A and 11B). For the dry season as well as goats and sheep, *Arachis hypogaea* L. was regarded as the topmost salient forage species with CSI values of 0.32, 0.28 and 0.30 respectively as well as nine other forage species with the topmost CSI values for targeted seasonal and livestock types (see Figs. 11C, 11D and 11E). Among the many underlying reasons given by local agro-pastoralists for their ranked forage plants including *P. pedicellatum* Trin and *A. hypogaea* L. discussed in the following Section 3.2, these two forage plants have been found to have very high nutritional quality such as high crude protein, crude fiber, ash content, calcium/carbohydrates, fatty acid, amino acid and in vitro digestibility profiles (Campos-Mondragón et al. 2009, Waziri et al. 2013). This may make them most suitable to livestock and in turn highly ranked by local farmers. As an annual, *P. pedicellatum* Trin tends to grow faster during the growing (rainy) season and has more abundant leaves compared to *Andropogon gayanus* Kunth (Waziri et al. 2013). The dominance of the Poaceae and Fabaceae families from which many forage species come do reflect their high forage potential, as reported in several ethnobotanical studies in the region (Zizka et al. 2015, Naah and Guuroh 2016) and elsewhere (Bahru et al. 2014, Nunes et al. 2015).

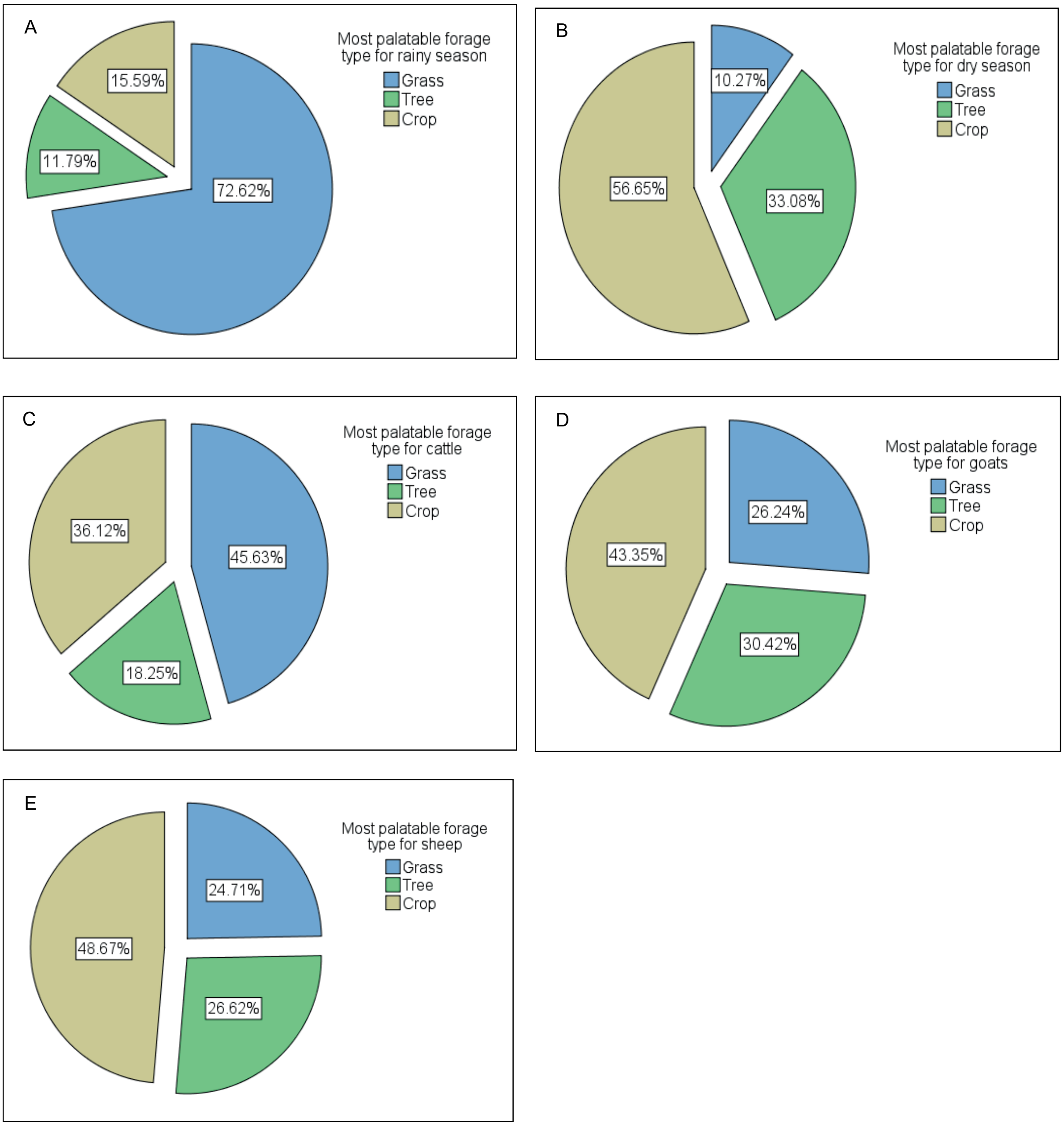

Fig. 10: Proportions of forage plants types ranked by local farmers as most palatable or suitable during rainy and dry seasons and for cattle, goats and sheep production.

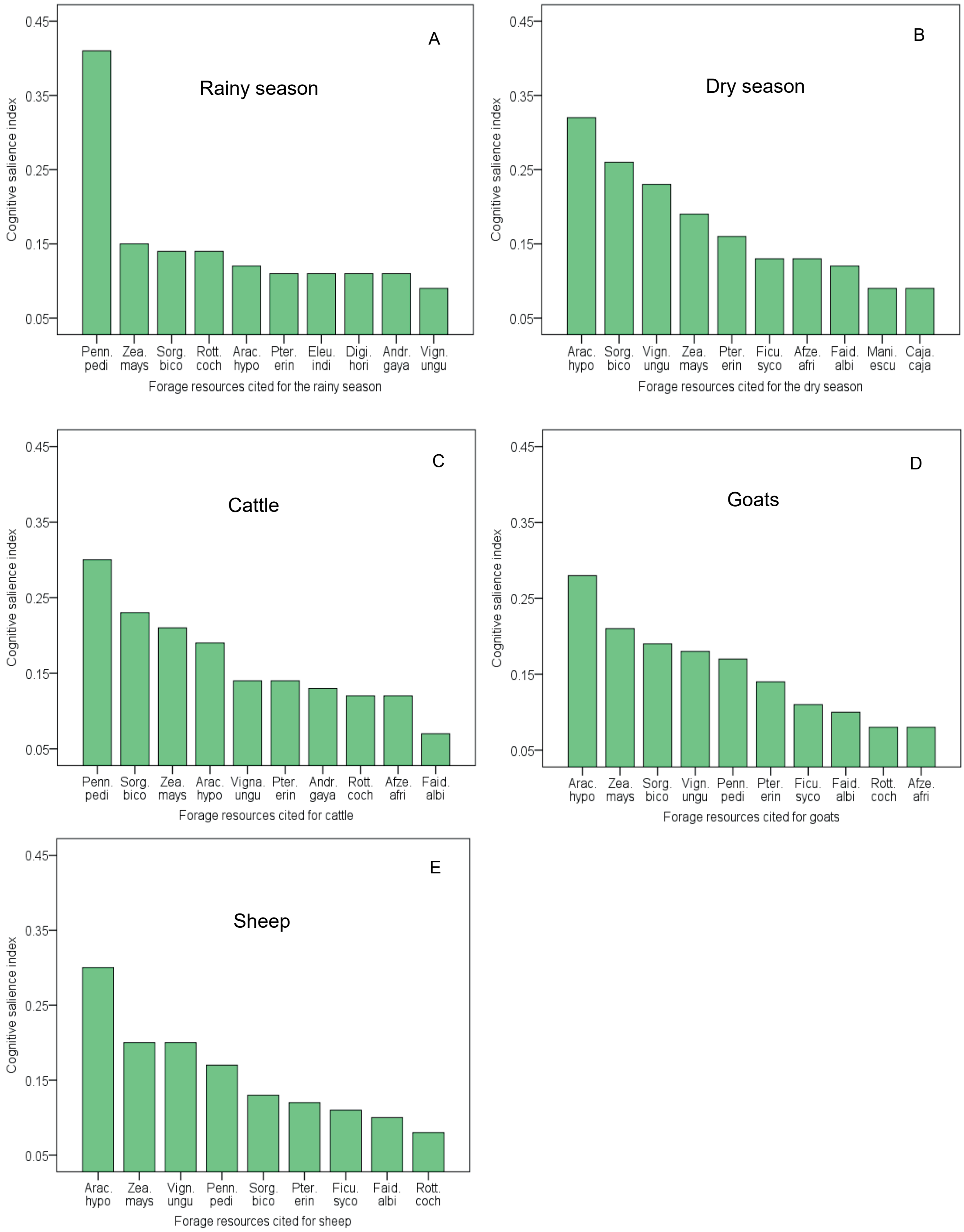
A
Rainy season
Cognitive salience index
0.45
0.35
0.25
0.15
0.05
Penn. pedi
Zea. mays
Sorg. bico
Rott. coch
Arac. hypo
Pter. erin
Eleu. indi
Digi. hori
Andr. gaya
Vign. ungu
Forage resources cited for the rainy season
B
Dry season
Cognitive salience index
0.45
0.35
0.25
0.15
0.05
Arac. hypo
Sorg. bico
Vign. ungu
Zea. mays
Pter. erin
Ficu. syco
Afze. afri
Faid. albi
Mani. escu
Caja. caja
Forage resources cited for the dry season
C
Cattle
Cognitive salience index
0.45
0.35
0.25
0.15
0.05
Penn. pedi
Sorg. bico
Zea. mays
Arac. hypo
Vigna. ungu
Pter. erin
Andr. gaya
Rott. coch
Afze. afri
Faid. albi
Forage resources cited for cattle
D
Goats
Cognitive salience index
0.45
0.35
0.25
0.15
0.05
Arac. hypo
Zea. mays
Sorg. bico
Vign. ungu
Penn. pedi
Pter. erin
Ficu. syco
Faid. albi
Rott. coch
Afze. afri
Forage resources cited for goats
E
Sheep
Cognitive salience index
0.45
0.35
0.25
0.15
0.05
Arac. hypo
Zea. mays
Vign. ungu
Penn. pedi
Sorg. bico
Pter. erin
Ficu. syco
Faid. albi
Rott. coch
Forage resources cited for sheep

Fig. 11: Cognitive salience indices of the 10 most commonly cited individual forage species by agro-pastoralists in descending order in 16 villages located in Northern Ghana and Southern Burkina Faso. Note: Penn.pedi=*Pennisetum pedicellatum* Trin, Zea.mays=*Zea mays* L., Sorg.bico=*Sorghum bicolor* (L.) Moench, Rott.coch=*Rottboellia cochinchinensis* (Lour.) W. D. Clayton, Arac.hypo=*Arachis hypogaea* L., Eleu.indi=*Eleusine indica* (L.) Gaertn, Andr.gaya=*Andropogon gayanus* Kunth, Pter.erin=*Pterocarpus erinaceus* Lam., Digi.hori=*Digitaria horizontalis* Willdenow, Vign.ungu=*Vigna unguiculata* (L.) Walp, Ficu.syco=*Ficus sycomorus* L., Afze.afri=*Afzelia africana* Smith ex Pers., Faid.albi=*Faidherbia albida* (Del.), Mani.escu=*Manihot esculenta* Crantz and Caja.caja=*Cajanus cajan* (L.) Millsp.

5.4.2 Salience of explicit criteria for valuating forage resources for livestock production and management among agro-pastoralists

We have found that local informants judged individual forage plants (see Section 3.1 above) based on a myriad of reasons. The findings of this study support our hypotheses that the local valuation of forage resources is based on several criteria during different seasons and for different livestock types. Among many other reasons, the healthy growth of livestock was consistently stated as the most important underlining criterion for ranking forage resources for all seasonal and livestock types (Table 3). However, the availability or apparency of forage resources, as a criterion for valuating them, is contingent upon the seasonal type considered by local informants. Thus, the fresh grasses and forbs were adjudged by local informants as very important because herbaceous forage species were readily available during the rainy season. This was also true for crops/crop residues and leaves of trees/shrubs which were seen as very suitable for feeding livestock in the dry season. This may also account for similar reasons outlined in Section 3.1 above. Additionally, the perceived livestock desires (e.g. cattle, goats and sheep) and forage palatability at a young phonological stage were very strong reasons for ranking of forage species (see Table 3). The reason of livestock growing fat after feeding on a particular forage plant is a very salient criterion for cattle. This may be explained by local agro-pastoralists' intention to sell cattle with fine skins and fat body conditions at high local market prices or to use especially bullocks for ploughing purposes (Table 3). A similar study on the use of local fodder flora in Pakistan also reported that woody vegetation (especially *Acacia nilotica* (L.) Willd. ex Delile and *Ziziphus mauritiana* Lam.) as also present in our study area) were the most preferred fodder species for goats and camel but not cattle and sheep due to their ability to satisfy, ever green nature and sweetness (Badshah and Hussain 2011). However, this studied failed to quantify the salience of these examples of criteria given by local farmers, unlike this study.

Table 3: The topmost 15 local valuation criteria provided by local agro-pastoralists and their respective cognitive salience indices (CSIs) for rainy season, dry season, cattle, goats and sheep. The bold figures represent CSIs more than 10 percent of the topmost valuation criteria mentioned.

Local valuation criteria	Salience RS	Salience DS	Salience cattle	Salience goats	Salience sheep
Health	**0.347**	**0.267**	**0.432**	**0.426**	**0.435**
Availability of grasses	**0.189**				
Animal desires	**0.154**	0.013			
Phenological stage	**0.118**				
Grow fat	**0.104**	0.078	**0.123**	**0.115**	**0.117**
Hunger	0.086	0.080	0.094	**0.106**	**0.102**
Energy provision	0.072	0.052	0.074	0.072	0.062
Natural food source	0.069	0.027	0.069	0.093	0.084
Taste	0.042	0.033	**0.111**	**0.108**	**0.101**
Milk production	0.024	0.02	0.032	0.027	0.030
Availability of crops and trees		**0.133**			
Unavailability of fresh grasses		**0.127**			
Nutrient (vitamins)			0.038	0.038	**0.100**
Good for our animals			0.034	0.034	0.034
Increased reproduction			0.021	0.027	0.016

5.4.3 Matching CSI values of local informants' data and ecological data on forage species: Any point of convergence?

The match of CSI_{ethno} and CSI_{plot} datasets in local landscape revealed divergent species compositions. Looking at only the 10 most salient plant species in both datasets, it is revealed that *Pterocarpus erinaceus* Lam, *Ficus sycomorus* L and *Afzelia Africana* were well recalled by local agro-pastoralists to have very good forage value in the interview-based dataset but they are much less represented in the plot-based data very low CSI_{plot} values or are completely missing.

Moreover, the interview-based data included not only trees and shrubs but were also dominated by grasses/forbs (e.g. *Pennistum pedicellatum* Trin) and crop-related forage plants (e.g. cereals and legumes) as very good forage resources. However, regarding the plot-based dataset, it is rather *Vitelliara paradoxa*, *Piliostigma reticulatum, Lannea microc*arpa and others which are commonly found and dominated in the plot-based dataset (Fig. 4A and 4B). These results could be explained by the fact that some species including economically useful trees may be present in the local environment but not necessarily considered favorable forage resources for sustainable livestock production. It was also reported by local agro-pastoralists that although e.g. *P. erinaceus* Lam and *A. Africana* were of very high forage value for livestock, these species are becoming fewer and fewer in numbers. This was confirmed by our vegetation sampling data since the afore-mentioned forage species were not recorded in many villages in both Ghana and Burkina Faso.

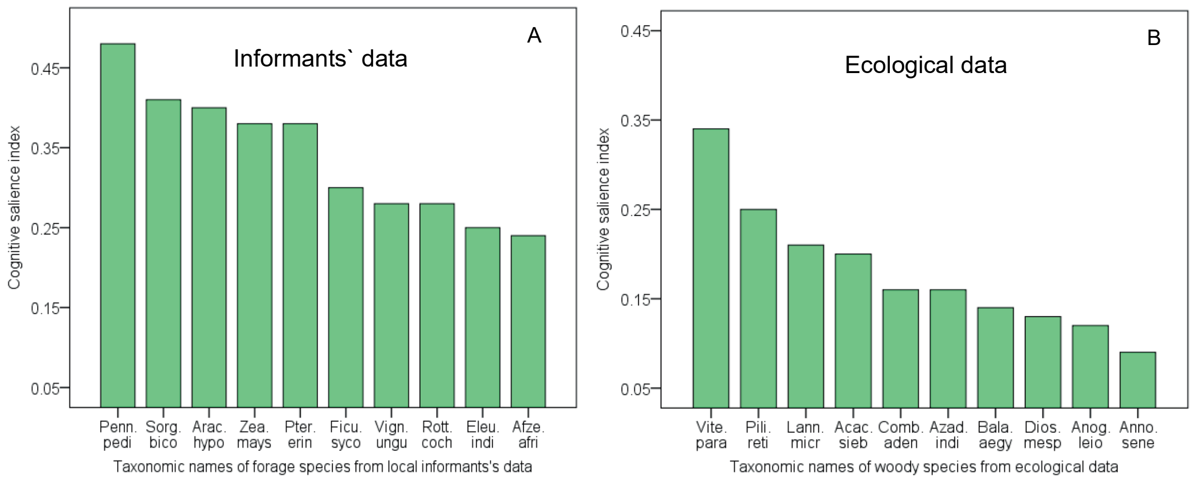

Fig. 12: Comparison of plant species composition for both the interviewed-based (A) and plot-based (B) datasets in all study sites within Northern Ghana and Southern-central Burkina Faso.

5.4.4 Determinants of citation of explicit valuation criteria for forage resources by local agro-pastoralists

Based on the AIC values obtained from established candidate global models, the aridity-based models were retained in the ‘best’ final models for all explanatory variables namely criteria for rainy season (Cri_{RS}), dry season (Cri_{DS}), cattle (Cri_{cattle}), goats (Cri_{goats}) and sheep (Cri_{sheep}) considered (see Appendix 6). This finding is not surprising because both aridity and ethnicity variables were found to be collinear since both variables were having similar dimension in terms of coverage in the study area (see Fig. 9). The retained aridity-based models were subjected to further analysis and discussion in this paper, since aridity class variable seems to significantly contribute to the variance explained in the citation of local valuation criteria for forage plants by agro-pastoralists as compared to the less influential ethnicity-based models. It was revealed that the main effects of aridity classes but not the interacting effects of it and gender, age, educational and residential status variables of the local informants were found to be significant. The compared delta AIC values of aridity- and ethnicity-based final models were found to be plausible since it was greater than two, as was similarly reported in Chapter 4.

Our results also revealed that climatic aridity had a strongly significant effect on the number of citation of local forage valuation criteria necessary for livestock production among agro-pastoralists during the rainy season (Cri_{RS}; X^2 = 70.17, DF = 3, p = <0.001, Table 4), dry season (Cri_{DS}; X2 = 107.17, DF = 3, p = <0.001, Table 4), for cattle (Cri_{cattle}; X2 = 58.92, p = <0.001, Table 4), goats (Cri_{goats}; X2 = 62.39, p = <0.001, Table 4) and sheep (Cri_{sheep}; X2 = 74.95, DF = 3, p = <0.001, Table 4). Thus, agro-pastoralists living in humid and dry sub-humid locations gave many different reasons for ranking their forage plants while those in semi-arid villages cited fewer reasons. The superior effect of the climatic aridity variable on the citation of local valuation criteria for forage resources by agro-pastoralists highlights how variable precipitation patterns markedly influence local perceptions at varied seasons and for different livestock types than that of the ethnicity variable.

Pairwise comparisons with adjusted p-values show that there are significant differences with respect to Cri_{RS} in Moist Semi-arid (MSA) and Dry Semi-arid (DSA) locations (p = <0.001, r (effect size) = 0.26). This was similarly observed between Cri_{RS} in Dry Sub-humid (DSH) and DSA (p = 0.001, r = 0.33), Humid (HUM) and DSA (p = 0.001, r = 0.30). There is, however, no significant effect of aridity on Cri_{RS} when compared between DSH and MSA, HUM and MSA and HUM and DSH locations (Ps > 0.05). Comparing the Cri_{DS} between MSA and HUM localities, the follow-up post hoc tests reveal that local agro-pastoralists living in the former rather cited significantly fewer Cri_{DS} than those in the latter location (p = <0.001, r = 0.18). A similar significant difference was found between MSA and DSH (p = <0.001, r = 0.17) villages as opposed to the same aridity classes in the

Cri_{DS} as explained above. We also found a significantly higher Cri_{DS} cited by those living in MSA, DSH and HUM than by local people residing in DSA areas ($P = 0.001$), showing a similar trend for the rainy season as well (see Chapter 4) for similar trend of LEK distributional patterns in woody and crop-related forage species (see Appendix 5).
With respect to the pairwise comparisons for Cri_{cattle} and Cri_{goats}, it was revealed that local agro-pastoralists inhabiting DSH, HUM and MSA environments cited a significantly higher number of local valuation criteria for suitable forage plants for cattle and goats consumption than that of the DSA areas (ps = <0.001). For the Cri_{sheep}, we found a similar pattern of local knowledge as explained for Cri_{cattle} and Cri_{goats} above. However, DSH and MSA and HUM and MSA locations are significantly different. The way in which the differences exist in various aridity classes as illustrated above is a testament of how varying climatic conditions encourage local farmers to have many more reasons for many forage species cited in humid areas as compared to fewer reasons for fewer forage species mentioned in drier areas, as such weather conditions directly affect forage species availability and distribution. This is also true for different valuation criteria for livestock considered for this study. The R_m^2 and R_c^2 calculated were rather found to be generally low. Depending upon the explanatory variable considered, the R_m^2 ranges from 21 percent to 25 percent while R_c^2 ranges from 23 percent to 26 percent of variance explained in the responses (see Table 4; Appendix 5).
Table 4: Aridity-based final model selection using generalized linear mixed-effects (GLMM). Results of testing fixed-effects of aridity class (dry semiarid-DSA, moist semiarid-MSA, dry sub-humid-DSH and humid-HUM) on number of local valuation criteria cited by agro-pastoralists for (I) rainy season (Cri_{RS}), (II) dry season (Cri_{DS}) and (III) cattle (Cri_{cattle}), while aridity class and educational background of informants influenced (IV) goats (Cri_{goats}) and (V) sheep (Cri_{sheep}) as metric of regional-level variance. The random component of village nested within aridity class variable was incorporated to account for site-specific variations. Detailed corresponding follow-up posthoc tests for the Analysis of Deviance results using Wald chi-square(X^2) tests were also calculated. Random effect: = ~1|Village/Aridity class. Marginal, $R_m^2 = R^2$ for variance explained by only fixed factors and Conditional, $R_c^2 = R^2$ for variance explained by both fixed and random factors.

(I) Cri_{RS}	Df	X^2	p
(Intercept)	1	13.00	< 0.001***
Aridity class	3	70.17	< 0.001***
Marginal, R_m^2 (%)	21		
Conditional, R_c^2 (%)	23		
(II) Cri_{DS}	Df	X^2	p
(Intercept)	1	8.61	< 0.001***
Aridity class	3	107.17	< 0.001***
Marginal, R_m^2 (%)	23		
Conditional, R_c^2 (%)	23		
(III) Cri_{cattle}	Df	X^2	p
(Intercept)	1	6.94	< 0.001***
Aridity class	3	58.92	< 0.001***
Marginal, R_m^2 (%)	23		
Conditional, R_c^2 (%)	26		
(IV) Cri_{goats}	Df	X^2	p
(Intercept)	1	8.19	< 0.001***
Aridity class	3	62.39	< 0.001***
Education	2	4.36	0.113
Marginal, R_m^2 (%)	24		
Conditional, R_c^2 (%)	26		
(V) Cri_{sheep}	Df	X^2	p
(Intercept)	1	9.32	< 0.001***
Aridity class	3	74.95	< 0.001***
Education	2	5.13	0.077
Marginal, R_m^2 (%)	25		
Conditional, R_c^2 (%)	26		

Note: *<0.05, **<0.01, ***<0.001

5.5 Conclusion

This study has not only looked at how local agro-pastoralists judge the value of available forage resources in their local pastures but also explored how environmental harshness (climatic aridity) affect their collective cognitive salience of these forage resources as well as their associated local valuation criteria in such under-researched West African savanna ecosystems. We also matched our ethnobotanical data set with the vegetation sampling dataset for clarity in understanding such forage-related LEK. Knowing which forage types (herbaceous, woody vegetation and crop-related forage plants) are suitable for various livestock (cattle, goats and sheep) and seasonal types (dry and rainy seasons) enables local agro-pastoralists to better plan and manage available forage resources in the face of changing local climatic conditions in a sustainable manner.

Given also our findings, local resource-users do not just behave in a ‘vacuum’ but consciously make their choices on the use of such limiting forage resources based on underlying reasons and prevailing circumstances for sustained livestock production and livelihood improvement. It is also revealed that environmental change has a significant effect on how forage resources are adjudged by local agro-pastoralists. Thus, those in humid and sub-dry humid villages generally provided many reasons for their ranked forage plants as compared to those living in moist and dry semi-arid localities. Our approach may help us appreciate how local land users perceive and utilize their forage resources in both periods of abundance and scarcity. Hence, local actions can be harnessed to better understand the global climate change dynamics so as to help increase efforts in the conservation of forage species for future generations. This is because management-related decisions taken on the utilization of declining forage resources by the local agro-pastoralists in our research region at the local level is extremely crucial in the context of global environmental change. Literature has shown that the role of development interventions for increasing adaptive capacity is important to better understand the relationship between poverty and vulnerability, which will inform policy decisions globally (Lemos et al. 2016). We thus conclude that a lot more attention should be given to LEK-related investigations in dryland ecosystems to ensure sustainable livestock production and to stimulate the scholarly debate about the resilience of the SES concept in natural resources management efforts.

6 Assessing forage species diversity, habitat distributions, abundance trends and ecological drivers from local agro-pastoralists' perspectives in West Africa's Savanna ecosystems

6.1 Chapter abstract and highlights

Assessing local agro-pastoralists' knowledge and perceptions on forage species diversity, habitat distribution, abundance trends and associated ecological drivers are fundamental to sustainable agriculture and livelihood improvement efforts. Notwithstanding, there has been little discussion on how smallholder farmers perceive the afore-mentioned ecological variables in the management of locally available natural forage resources within the study area. This study, thus, aims to estimate forage species diversity, analyze habitat types of forage resources, investigate abundance trends of available forage resources, identify local ecological drivers and document conservation measures based on the perceptions of local agro-pastoralists. In doing this, we covered 526 informants in sixteen villages, consisting of seven villages in northern Ghana and nine of them in southern-central Burkina Faso. Data were analysed via descriptive statistics, bivariate correlation analysis and cognitive salience index calculation to disentangle the dynamics of local responses to the ecological variables considered in this study. Our results indicated that the local agro-pastoralists exhibited extensive knowledge in forage species diversity, habitat types, abundance trends and ecological drivers. It was also established that local agro-pastoralists associated their cited forage plants more with upland topography than lowland and combined landscapes of the two topographic positions. According to them, approximately 82 percent of reported items were considered to be commonly available in local landscapes, while most of them indicated that available forage resources have been experiencing a gradually increasing trend over the past few years. It was also revealed that rainfall variability, tree cutting and drought were the topmost perceived threats causing changes in the trends of forage species abundance. Given our findings, local actions of agro-pastoralists could potentially have practical implications at the global level in favour of biodiversity conservation.

Highlights:

- This study illustrates highly diverse forage species in West Africa's savanna ecosystems.
- Local agro-pastoralists possess extensive forage-related knowledge of the habitat distribution and associate them more with upland topography.
- Majority of the forage resources cited are perceived to have gradually increasing trend over time.
- Rainfall variability, tree cutting and drought are the topmost perceived threats causing changes in the abundance trends of forage species.
- Local agro-pastoralists are well aware of local measures in favour of conservation of forage plants for livestock grazing.

6.2 Introduction

A plethora of literature abounds with evidences that future projections and scenarios of global climatic conditions point to increasing incidences of unpredictable precipitation patterns, drought spells, overgrazing, severe mean annual temperature rises, intermittent floods and land degradation particularly in global drylands (IPCC 2007, Reynolds et al. 2007, Maestre et al. 2012, IPCC 2013), and such changes are unbeneficial (IPCC 2013). Hence, tropical West Africa, in particular, has been experiencing a significant increase in such challenging anthropogenic and natural incidences (Niang et al. 2014) and human population growth (Mertz et al. 2011). This then results in severe changes in the vegetation composition and species cover in West African Savanna ecosystems (Zerbo et al. 2016). Smallholder farmers in this region and other developing countries are thus considered as disproportionately vulnerable to climate change owing to its direct effect on their crop and animal productivity, as well as negative consequences on their food security, income and general well-being (Vignola et al. 2015). Being able to make use of a diverse portfolio of management strategies, and to have diversified sources of income, may greatly increase pastoral livelihood security, particularly in a highly variable environment (Kuhn et al. 2010, Martin et al. 2014). Climate change and variability especially e.g. scarcity of water might lead to reduced supply of essential ecosystem services including forage provision for livestock production while increasing demand for these ecosystem services from the vegetation.

Apart from climate change and variability, smallholder farmers are also faced with non-climatic stressors, e.g. land use and socio-economic factors (Antwi-Agyei et al. 2014). However, many local smallholder farmers in West African Savannas engage in farming practices which contribute to maintenance of complex biological diversity including agro-biodiversity, resulting in increased adaptive capacity to cope with and to recover from extreme weather condition (Altieri and Koohafkan 2008). To ensure effective sustainability and biodiversity conservation efforts in natural resources management, understanding the SES conceptual framework is vitally critical (Rissman and Gillon 2016). Studies have shown that land users' local ecological knowledge (LEK) on forage plants is of critical importance for their adaptive rangeland management (Müller et al. 2007, Linstädter et al. 2013). Research has also shown that agro-pastoralists' LEK of forage resources is an essential component of management decisions (Wesuls and Lang 2010, Linstädter et al. 2013), and plays a crucial role in (agro-)pastoralists' adaptation to climate change (Naess 2013). Identifying crucial aspects of an adaptive natural resource management appears a promising approach for developing mitigation strategies for negative consequences of projected climate change in West Africa.

Despite the importance of LEK on forage plants, very little research has been done on how local agro-pastoralists perceive forage species diversity, abundance, habitat distribution and ecological drivers influencing their changing numbers over the years in rural West Africa's Savannas. This ethnobotanical study was not intended to investigate causalities of the above-referenced ecological variables in the research region. Thus, it was intended to address the following specific research objectives:

1. To estimate forage species diversity based on local agro-pastoralists' LEK.
2. To analysize local agro-pastoralists' perceptions on habitat types of forage resources.
3. To investigate how local farmers assess the abundance and trends of available forage resources.
4. To identify local ecological drivers responsible for changes in trends of forage plants communities over time.

5. To document conservation measures put forward by local agro-pastoralists for sustainable forage resources utilization.

6.3 Materials and methods

6.3.1 Study area description

The study area covers almost the entire gradient of climatic aridity within West Africa's agro-ecological zone of Sudanian savannas, and reaches from northern Ghana to central Burkina Faso (Fig. 13). Thus, the northern Sudanian zone is largely semi-arid, while the climatic conditions in the southern Sudanian zone vary from dry sub-humid to humid. In total, the study area covers a distance of about 530 km from north to south (Ferner et al. 2015) and its climate is seasonal in nature. Outside protected areas, the sparse tree layer mostly consists of economically important trees and shrubs such as the shea nut tree, *Vitellaria paradoxa,* or the baobab, *Adansonia digitata* (Traoré et al. 2013, Ouédraogo et al. 2015). Some tree species which contribute to ruminant nutrition include *Afzelia africana, Pterocarpus erinaceus* and *Piliostigma sp* for cattle in particular while *Balanites aegyptiaca, Ziziphus mauritiana* and *Acacia sp* are primarily fed on by small ruminants (Zampaligré et al. 2013). The grass layer in the northern Sudanian pastures mostly in Burkina Faso is dominated by *Andropogon pseudapricus, Loudetia togoensis, Aristida kerstingii, Dactyloctenium aegyptium* and *Digitaria horizontalis* while the southern Sudanian zone is dominated by *Andropogon sp., Hyparrhenia* and *Schizachyrium* sp are co-dominants in both Ghana and southern Burkina Faso (Kagone 2006, Oppong-Anane 2006, Zampaligré et al. 2013). The singular distinguishing vegetation feature is that, the northern Sudanian zone constitutes mostly patchy and many bare grounds (Zampaligré et al. 2013) and fewer tree species while southern Sudanian zone has a continuous herbaceous cover interspersed with fire-resistant and broad-leaved trees (Oppong-Anane 2006).

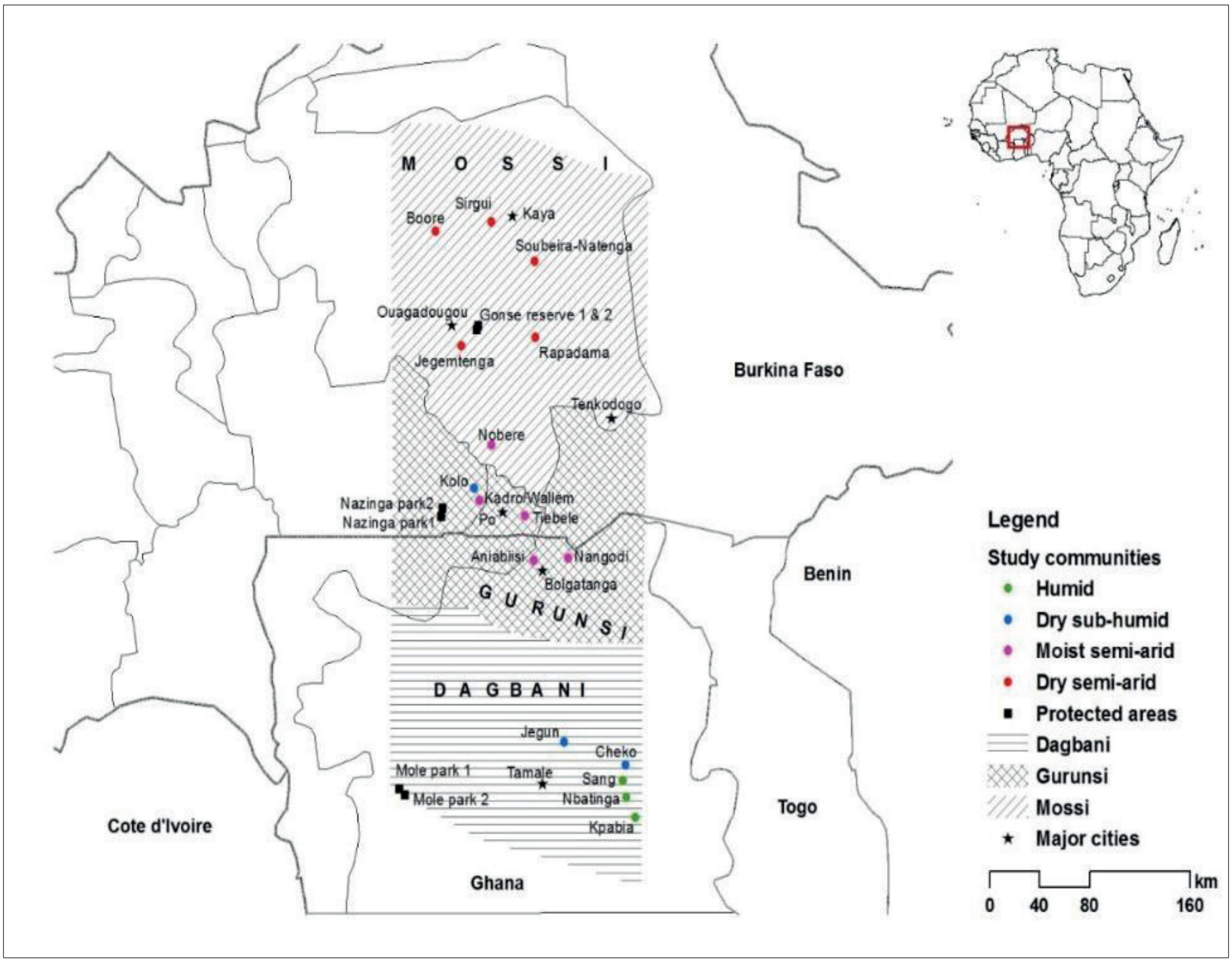

Fig. 13: Study area in the West African Sudanian savannas comprising northern Ghana and south-central Burkina Faso, and positions of 16 study villages across three major ethnic groups (Dagbani, Gurunsi and Mossi) located along a gradient of climatic aridity. The aridity classes (see study communities and climatic aridity) are defined based on aridity indices of villages. For each village, its aridity class is shown, following the UNEP aridity classification system (UNEP 1997) and our own subdivision of semi-arid class into moist and dry semi-arid classes. Source: Map by Gerald Forkuor.

6.3.2 Selected ethnic groups and climatic zones

The study area is inhabited by three dominant ethnic groups roughly replacing each other along the north-south gradient of climatic aridity (Fig. 13), i.e. the Mossi in central and southern Burkina Faso, the Gurunsi living on both sides of the border between Burkina Faso and Ghana, and the Dagbani in northern Ghana. While these ethnicities share comparable agro-pastoral practices, the relative importance of livestock-generated income slightly varies across them. Livestock husbandry (mainly cattle, sheep and goats) constitutes a crucial aspect of the livelihood strategies of rural people living in semi-arid West Africa (Turner et al. 2014). In Ghana, almost every household rears a few animals for home consumption (small ruminants) and as financial capital saving in case of crop failures, as may be the case for Burkina Faso. Cattle rearing is more or less a preserve for the well-to-do individuals in rural communities (see Chapter 4).

The Mossi mostly inhabit dry semi-arid sites with the harshest environmental conditions in the study area (Fig. 13); they contribute over 50 percent to Burkina Faso's total population (Sop et al. 2012). Traditionally, their rural economy is dominated by subsistence agriculture, with millet, sorghum, maize and cowpea being the main crop plants (Sop et al. 2012).

The Gurunsi ethnic group consists of sub-ethnic groups including Frafras and Nabit in northeastern Ghana only, while Kasenas inhabit both northeastern Ghana and southern Burkina Faso. The Gurunsi group contributes about 5 percent of the total population of Burkina Faso (Kristensen and Balslev 2003) and a similar proportion in Ghana. Although these sub-ethnic groups have linguistically distinct dialects yet they have similar social, economic and religious practices. The Gurunsi are known to be crop farmers but later adopted an agro-pastoralist lifestyle from Mossi and Fulani ethnic groups who migrated to the south to look for better forage resources for their livestock and fertile lands for cultivation (Kristensen and Balslev 2003, Kristensen and Lykke 2003). Within the study area, the Gurunsi mainly inhabit relatively moist semi-arid environments.

Furthermore, the Dagbani ethnic group inhabits both humid and dry sub-humid sites, representing the most humid conditions within the study area. They constitute about 60 percent of the population of Ghana's Northern Region and 16.5 percent to its total population (Langer and Ukiwo 2007). Their rural economy is majorly based on agro-pastoralism (involving crop farming and livestock keeping) since the open savanna ecosystem is suitable for such a farming system. With better rainfall regime than other parts within the study area, crop productivity is quite high among Dagbani farmers. Due to the patriarchal dominance of Dagbani tribe, men own most of the large ruminants especially cattle while their women engage in rearing of goats and sheep, and cultivate mostly 'female crops' such as vegetables, maize, beans, groundnuts, rice, sorghum and potatoes (Apusigah 2013).

6.3.3 Ethnobotanical survey design

We administered structured ethnobotanical questionnaires to local agro-pastoralists regarding their perception and knowledge on habitat types, current abundance trends and local ecological drivers of the quantity of forage resources. Following recommendations by Teddlie and Yu (2007), we applied a stratified random sampling design to collect representative data across ethnic groups, gender affiliation and age classes in particular. We randomly selected five study villages per ethnic group in our study area, and further stratified per village into gender and age-class (Fig. 13). Several LEK-related studies usually target the household heads who are deemed to be have more information and the less influential social groups such as the young boys and girls and women are left out in the primary data gathering process (Kristensen and Lykke 2003). However, this study tries to overcome this challenge by covering a broad spectrum of these varied social groups.

The ethnic and gender stratifications were done based on dominant ethnic groups (Dagbani, Gurunsi and Mossi) and gender (males and females) respectively. For age stratifications among local agro-pastoralists, we adopted age class definitions from previous studies in West Africa's Sudanian savannas (Eguavoen 2013) and distinguished informants into young (15-35 years), middle-aged (36-55 years) and old adults (>55 years). Field research was undertaken between October to December 2012 and July to October 2013. This stratification of informants was replicated in each study site (village). In sum, we covered 526 informants in sixteen villages, consisting of seven villages in northern Ghana and nine of them in southern-central Burkina Faso.

6.3.4 Sampling procedures for obtaining ecological information from agro-pastoralists

Based on the citation of the forage resources (herbaceous plants, woody vegetation and crop-related plants) by the local agro-pastoralists via a free list technique outlined in Chapter 4, crucially important ecological parameters were obtained from them. For instance, habitat types, current abundance, trends in abundance and ecological drivers to changes of forage resources available in local landscapes over the few past years were recorded. Reading the list of cited forage plants back to them during the ethnobotanical interviews, the local agro-pastoralists were specifically asked to indicate where each forage species was found in their environs, be it highland, lowland or both areas.

With respect to the abundance of the cited forage species, we asked local agro-pastoralists to indicate whether such cited forage species were many, few or rare within their vicinity at the time of the interviews. It has been reported that local pastoral farmers commonly use terms like increasing, decreasing or not changing in assessment of species trends (Roba and Oba 2009). Thus, for each species mentioned, we asked them to tell us whether they were: (1) many in number (common), (2) few in number (not common) and (3) rare (very difficult to find). Regarding the changing trends of abundance of these forage species, the local agro-pastoralists were asked to provide information on whether the forage plant communities have changed over the past years or not. We specifically asked the local agro-pastoralists to indicate whether the trends of changes in the abundance of forage plants have: increased rapidly (2), increased gradually (1), remained stable (0), rather decreased gradually (-1) and decreased rapidly (-2). It has been reported that local pastoral farmers commonly use terms like increasing, decreasing or not changing in assessment of species trends (Roba and Oba 2009).

To extract more information from the local people, we too asked them to provide possible reasons why they thought that their forage resources were perceived to be either increasing, decreasing or remain stable over the years. This was done to better understand local ecological drivers to changing quantity and/or quality of forage resources experienced by these local farmers in the face of global environmental change. Finally, they were asked to describe their own solutions, if any, with regards to the current abundance trends situation of their forage resources.

6.3.5 Data analysis

We estimated the diversity of these forage species in the studied communities using four diversity indices such as species richness, species evenness, Shannon-Wiener diversity index (H') and Simpson's diversity index (SDI). For species richness (S), it represents the number of forage species via the ethnobotanical interviews in a village irrespective of whether a particular species is abundant or not, as also done by Zerbo et al. (2016). Thus, S = N, where N = number of species per village. With respective to species evenness (E), it is the ratio of Shannon's index to the natural log of S. Thus, E = H'/In (S). This reflects the balance in the distribution of individuals forage species cited by local agro-pastoralists in the context of this study, which is independent of the frequency of species occurring in interviews in a village. When E is close to zero, a forage species is very similar while one value indicates quite different forage species composition (also see Zerbo et al. 2016). Regarding Shannon Wiener's diversity Index (H') estimation, it is also known as alpha diversity and defined as follows: H' = -Sum (Pi*In(P*i*)), where P*i* is the proportion of individuals belonging to the ith forage species (relative abundance of forage species) per village. As for Simpson's diversity index (SDI), is also known as the Beta diversity index, whereby it is mathematically represented as: SDI = Sum (Pi^2).

As investigating the causalities of the ecological variables is not a focus of this study, we conducted bivariate correlation analysis to determine relationships between the diversity metrics of these forage species reported by the local agro-pastoralists in the West Africa's savannas. Given the lack of normality in some of the variables, and coupled with the relatively small sample size used in this correlation analysis, we employed Kendall's tau, a non-parametric correlation which is considered to be a better estimate of the correlation in the sampling population instead of the popularly used Spearman's rho statistic (Fields, 2013). We additionally conducted bootstrapping to obtain robust confidence intervals (CIs). The significance level for correlation coefficients was assessed at $P < 0.05$). The collected data on the agro-pastoralists' perception of habitat distribution, abundance trends, ecological drivers and conservation suggestions were quantitatively analyzed using the Statistical Package for the Social Sciences-SPSS vs. 23 (Fields 2013). We thus generated descriptive statistics including cross-tabulations and figures. For perceived ecological drivers and traditional conservation measures, we performed Cognitive salience index (CSI) for responses provided by local agro-pastoralists as also in the case of forage-related valuation criteria in the same West African sub-region.

6.4 Results and discussion

6.4.1 Forage species diversity from species citations of local agro-pastoralists

Out of a total of 8,881 forage species elicited from the local agro-pastoralists for livestock grazing in sampled rural communities, 8,323 of them are known scientifically, representing 94 percent. For the known forage species, we recorded 194 different forage species, belonging to 151 genera and 52 families (see Appendix 15). The most represented families in the recall of local agro- pastoralists (see Appendix 13) consisted of Poaceae (37 forage species), Fabaceae (34) and Malvaceae (11), as similarly reported in the study area by Zizka et al. (2015). The most dominant genera of forage species cited included the *Acacia sp* (7 forage species), *Ficus sp* (6) and *Andropogon sp* (5). Our study also reported 558 items, corresponding to 6 percent which were only vernacularly known but not scientifically identified, resulting from the unavailability of cited forage species at the time of the field research.

As for the site/village-specific diversity of forage species, we recorded higher species richness in villages where Dagbani informants were present while those informants in Gurunsi- and Mossi-dominated villages reported lower species richness. For instance, the highest number of forage species was cited in Sang while the lowest number of species was cited in Nangodi. This could be indicative of the predominant role local climatic conditions play in the distributional patterns of forage-related LEK among local agro-pastoralists in the research region (Chapter 4). In a similar semi-arid Savanna ecosystem in South Africa, it was found that agro-pastoralists had extensive perception and ecological knowledge on the grass compositions in three different regions in Botswana (Kgosikoma et al. 2012).

Given our findings, it was evident that forage species richness was significantly correlated with the Shannon Wiener diversity index and Simpson's diversity index; while it has an insignificant negative relationship with forage species evenness (see Table 5). Also, forage species evenness was significantly related to Simpson's diversity index but insignificantly correlated with Shannon Wiener diversity index (see Table 5). It was also revealed that Shannon Wiener diversity index had a high significant relationship with Simpson's diversity index (Table 5). These location-specific biodiversity metrics of the forage plants depict the vegetation dynamics pertaining to villages located in both Burkina Faso and Ghana (see Appendix 10).

Table 5: Correlation matrix illustrating various species diversity metrics for forage species cited by local agro-pastoralists resident in varied rural communities in northern Ghana and southern-central Burkina Faso.

Diversity metrics	Species richness	Species evenness	Shannon's index	Simpson's index
Species richness	1	-.019 [-.393, .452]	.735** [.379, .950]	.502* [.136, .749]
Species evenness	16	1	.327 [-.212, .775]	.549* [.133, .838]
Shannon's index	16	16	1	.775** [.402, .891]
Simpson's index	16	16	16	1

Note: N = Sample size = 16 villages, ns = not significant (P >.05), * P < .05, ** P < .01, *** P < .001. Bias correlated and accelerated bootstrap (BCa) 95 percent CIs reported in brackets. Unless otherwise stated, bootstrap results are based on 1000 samples.

6.4.2 Perception of agro-pastoralists on habitat distribution of forage resources

Our results revealed that the local agro-pastoralists exhibited extensive knowledge and understanding of the habitat distribution of cited forage resources available in the local landscapes. As LEK is unevenly distributed among its holders (Briggs 2005, Ayantunde et al. 2008), we expected to find considerably varied responses among different agro-pastoralists for habitat distribution of a particular forage species. Thus, there were varying responses given with respect to where to find similarly cited forage species by local agro-pastoralists. Considering the upland habitat type, 47 percent of cited forage species were believed to be associated with it, as compared to 25 percent for the lowland areas and 28 percent considered to be suitable for both habitat types (Fig. 14). These findings reflect how local folks hold different opinions regarding where to suitably find forage plants based on their personal life experiences.

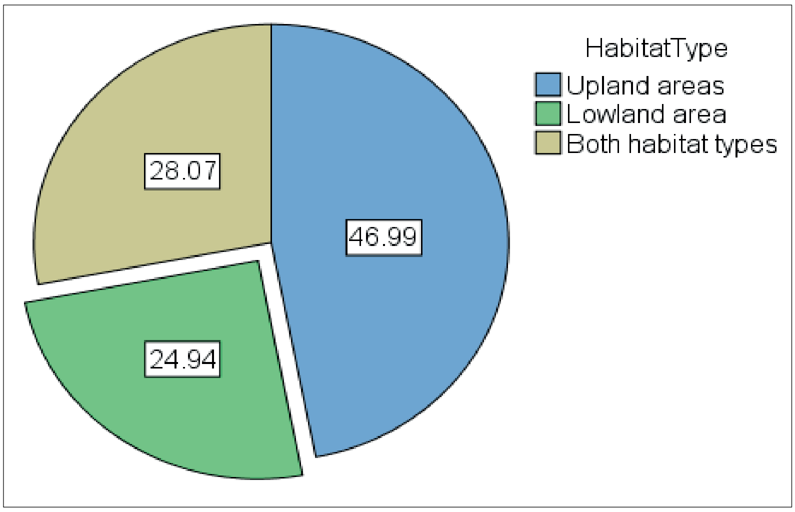

Fig. 14: Percentage of forage species citations by local agro-pastoralists based on habitat types.

6.4.3 Agro-pastoralists' assessment of the forage species abundance and their trends

In assessing the abundance of available forage species for livestock grazing by local farmers, they exhibited different views on whether a particular species is common or rare in number. However, approximately 82 percent of the items reported by the local agro-pastoralists were considered to be commonly available in their landscape (many). Those items which were said to be only few in number with respect to their availability represented 17 percent while 1 percent of the items were reported to be rare. For instance, crop-related forage sources such as the commonly farmed cereals (*Sorghum bicolor* (L.) Moench and *Zea mays* L.) and legumes (*Arachis hypogaea* L. and *Vigna unguiculata* (L.) Walp were among the topmost ones in the three categories of the species abundance cited by local agro-pastoralists as compared to the herbaceous and woody forage species (Fig. 15). This suggests that crops/crop residues availability is strongly modulated by rainfall variability, as good rains would lead to better yields and vice versa for bad rains. Also, depending on whether a particular informant grows any of these crops on small or large farmlands he or she will see them as many or few or rare. Moreover, these food and cash crops do have competing uses for both humans and livestock. For the few category, *Ficus sycomorus* L. topped the forage species cited while other regarded it as equally being many in number. Our findings are supported by studies which suggested that LEK is not only unique to different communities (Fernandez-Gimenez 2000) but also differs from an individual to another within the same community (Kgosikoma et al. 2012).

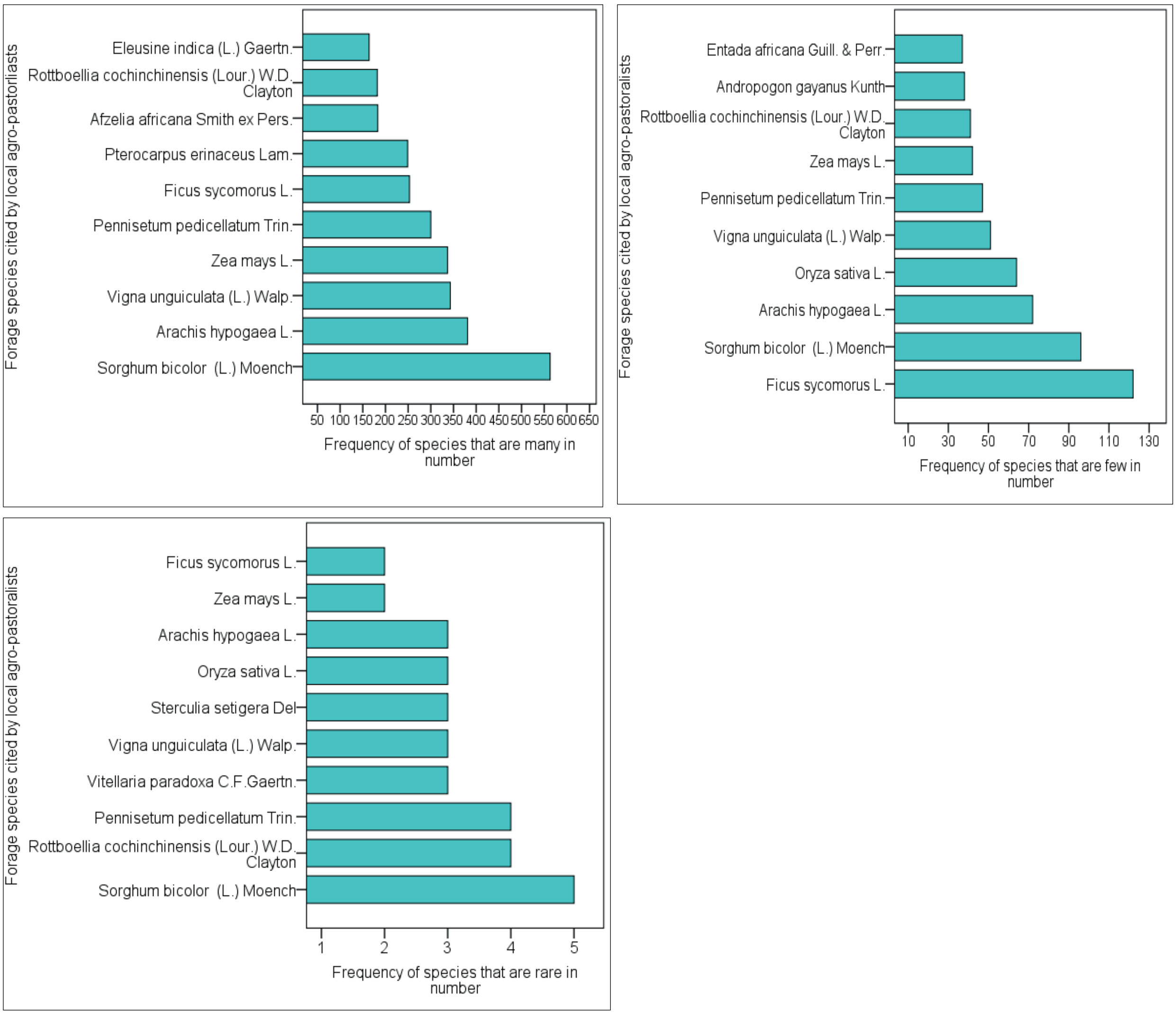

Fig. 15: Local agro-pastoralists' perception on the abundance levels (many, few or rare) of ten most frequently cited forage species in both Ghana and Burkina Faso.

Furthermore, changes in the abundance of forage resources over the past few years were generally perceived by local agro-pastoralists to have gradually increasing trend, representing 47 percent of the cited species. Our study also revealed that a high 33 percent of items were believed by the local informants to be gradually decreasing over the years. On the other hand, 11 percent of the reported items were said to be increasing rapidly while 5 percent of the cited items were perceived to be stable and 4 percent with decreasing rapidly (Fig. 16). These findings reflect a healthy assessment of the abundance trends of forage resources by agro-pastoralists as majority of them hold the view that cited forage species are either gradually increasing or decreasing, reflecting near-natural phenomenon as compared to fewer number of them who believe some forage species are rapidly increasing or decreasing, which could be exaggerated by the informants as at the time of the ethnobotanical interviews. It was also interesting to find that over 10 percent of the cited forage species was rather increasing rapidly while 5 percent of the forage species was either stable or decreasing rapidly, indicating the need to apply sustainable measures in the use of the forage resources. Those informants who are unaware of the varying trends should be educated to take interest in environmental issues, as they did not really bother about this category of plant species in their local communities.

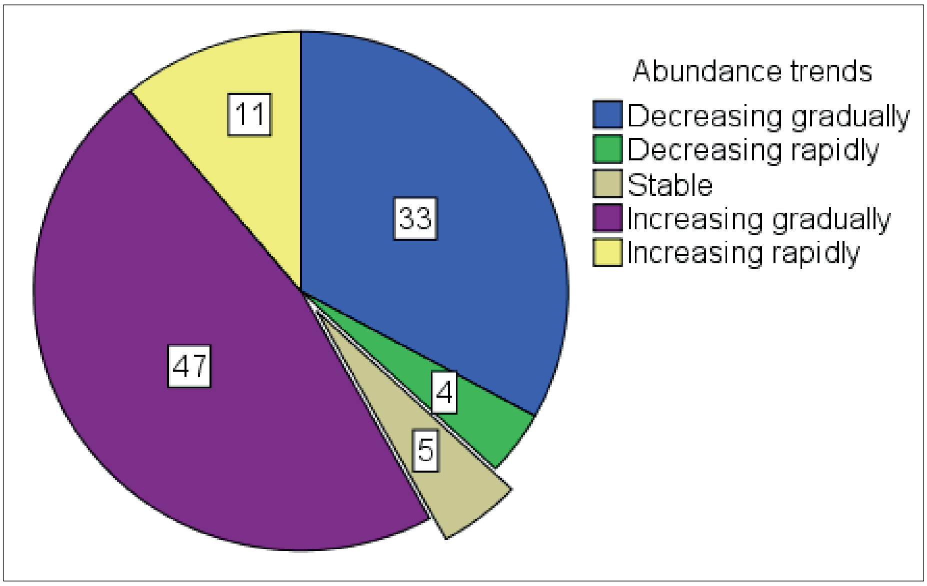

Fig. 16: Pie chart illustrating local agro-pastoralists' perceptions on abundance trends of forage species in the study area.

6.4.4 Local ecological drivers to changing abundance trends of forage resources

When local agro-pastoralists were asked to indicate why they perceived the forage resources to be increasing gradually/rapidly or decreasing gradually/rapidly or being stable, their reasons were varied among them as well (Fig.17). Our results amply showed that rainfall variability was the topmost threat causing changes in the trend of forage species abundance in the sampled rural communities. Also, tree cutting, drought, agricultural expansion and bushfires were perceived to be highly salient ecological drivers to changes in the abundance of forage resources (Fig. 17). These multiple ecological drivers mentioned by the local agro-pastoralists are not only limited to Ghana but also apply to Burkina Faso, which shows commonalities and the importance of these ecological drivers to subsistence farming activities in the study area Our study confirms rich knowledge exhibited by local people with respect to local vegetation dynamics so as to cope with rainfall variability and grazing pressure, as also reported elsewhere in Africa (Davis 2005, Oba and Kaitira 2006).

Rainfall variability (e.g. later rains or disproportionate down pour of rains within a short period of time) was reported to be responsible for poor crop yields leading to either rapid or slow decreasing trends in the availability of crop residues. Apart from rainfall variability and drought, deforestation without replacement with new seedlings, bushfires and overgrazing also lead to rapid or gradual decline of herbaceous and woody forage plants for livestock grazing in the sampled rural communities in both countries. However, abundance of crop-related, herbaceous and woody forage plants is usually on the ascendency when there are good rains (well spread out rainfall pattern, starting early and ending later in a year). For the mostly dry semi-arid villages in Burkina Faso, drought incidences have been widely reported as very serious threats which lead to declining trends in the availability of forage resources.

On the other hand, the local agro-pastoralists also attributed the rapid or gradual increase in the abundance of crop-related forage plants to agricultural expansion, human population growth and the application of chemical fertilizers or organic manure (less cited reason) to counteract the widespread problem of poor soil fertility. Other informants also attributed the various changes in the abundance of forage species to a natural phenomenon (involving germination, natural death, etc.). Our findings are supported by literature, which indicated that threats to the abundance of woody vegetation and forage plant species are a combination of anthropogenic and natural causal factors such as agriculture, overgrazing, deforestation, bushfires, droughts and so on (Gouwakinnou et al. 2011, Bahru et al. 2014). However, these studies failed to quantify the salience of these multiple ecological drivers to the local people's perspectives on the abundance trends of botanical resources (see Appendix 11).

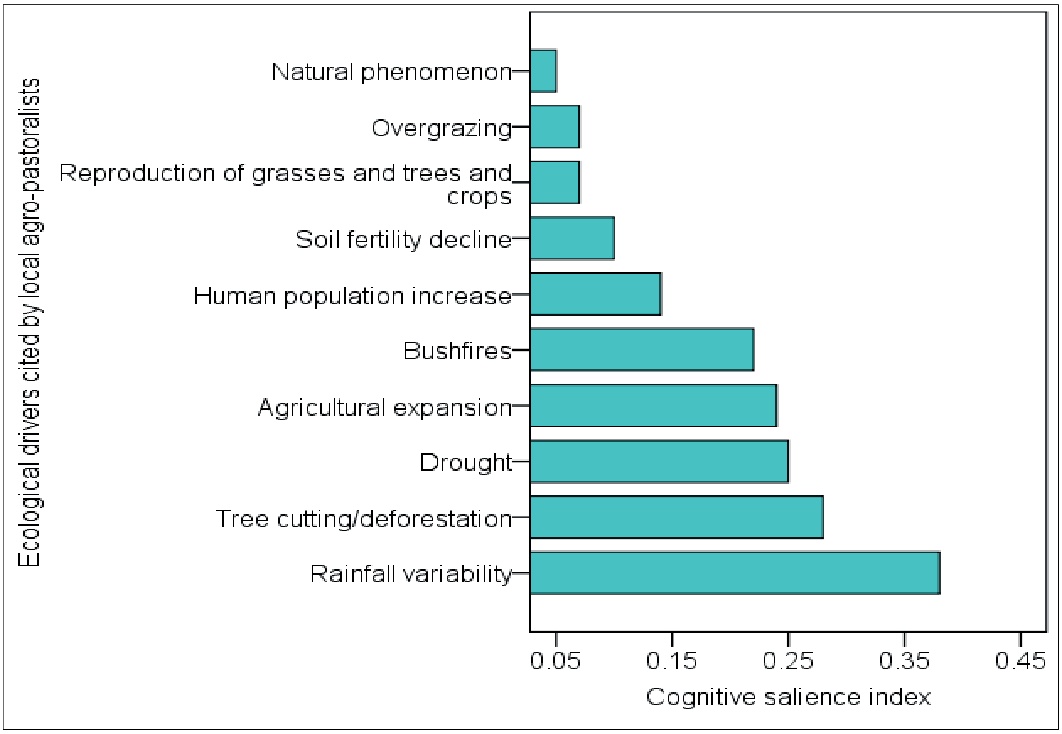

Fig. 17: Dominantly perceived ecological drivers to forage abundance trends according to local agro-pastoralists in the study area.

6.4.5 Forage resources conservation suggestions put forward by local agro-pastoralists

This study revealed that local agro-pastoralists were quite aware of their own actions that could influence the changing abundance of the natural forage resources. Moreover, the local informants suggested means through which their rich LEK in the traditional management and regulation of plant resources including forage plants could be applied (see Appendix 12). This is necessary for them to tackle negative effects of the ecological drivers to changing forage plants communities especially crops. One of the topmost suggestions made by local agro-pastoralists was that cutting down of trees for charcoal production and fuel wood should be stopped, while afforestation of useful trees should be encouraged by fellow farmers to increase the frequency of rainfall incidences and increase soil fertility. It was also reported in Ethiopia that felling of useful trees and shrubs especially for fuel wood or charcoal production by inhabitants is strictly prohibited except with permission from their local chiefs (Bahru et al. 2014). For the increase of the numbers of trees and shrubs, local informants recommended that transplanting of useful economic and fruits trees (e.g. mangoes, oranges, shea nuts etc.) in the study area.

Considering the dangers of indiscriminate bush burning inherent in the study region (e.g. burning could ‘chase’ away the rains), it was also suggested that bushfires should either be avoided completely or early bush burning be done to curtail intensive destruction of available dead and living forage materials. Others even added that culprits when caught burning the environment for whatever reason should be severely punished as a deterrent to others.

To increase their crop harvests, it was intimated that many farmers should practice crop rotational farming (e.g. *Sorghum* sp. vs soybeans) to control the presence of *Striga* sp. In this vein, application of chemical fertilizer and/or organic manure (e.g. cow dung and goat droppings) to their farmlands should be used to increase crop yields. To overcome poor soil fertility, shifting cultivation and/or fallow management are also recommended as a good farming practice to cultivate more food and cash crops to feed both humans and livestock. Also, no more use of weedicides was suggested since they kill many grasses indiscriminately. However, their moderate use as well as avoidance of overgrazing should be encouraged although it might be difficult to get a consensus on that, as claimed by some informants.

Also, the local people were of the opinion that public sensitization/education on the consequences of bushfires (destruction of soils, grasses and trees), weedicides and tree cutting should be conducted preferably by agricultural extension officers. Additionally, creation of alternative economic opportunities via government pro-poor interventions such as fertilizer subsidies, farm implements (tractors), accessible funds (money) and so on to illiterate-dominated rural communities for poverty allevaition and livelihood improvement.

Regarding the issue of inter-annual rainfall variability, some local informants rather said that they needed to pray or sacrifice animals for more rainfall through God's or small gods' (ancestors') intervention since no one has control over changing rainfall patterns. Others also suggested that they should do more irrigation on their farms to counteract current irregular rainfall patterns. A respondent in Aniabiisi village explained that it is God who gives all humans these plants and He determines their abundance (see Fig. 18). It is thus amply evident that indigenous management strategies employed by local agro-pastoralists will go a long to ensure efficient utilization and conservation of the rangeland resources, as also suggested by Bahru et al. (2014).

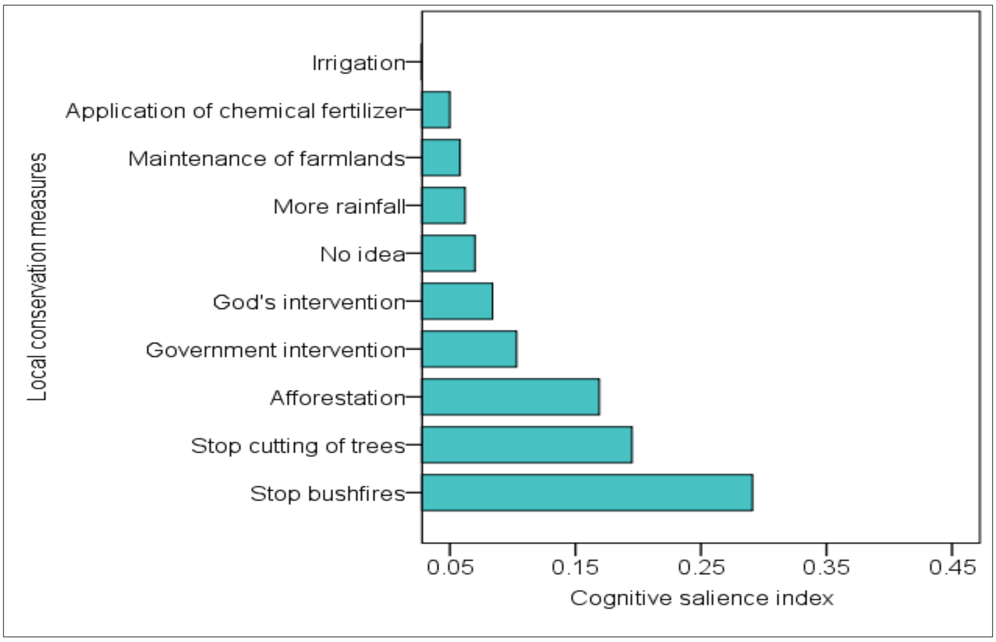

Fig. 18: The topmost local conservation measures of forage resources according to agro-pastoralists in the study area.

6.5 Conclusion

This present study amply illustrates the assessment of forage species diversity, their habitat distribution and abundance trends as well as associated predominant ecological drivers in rural West Africa from an ethnobotanical viewpoint. The local agro-pastoralists demonstrated a deep understanding of the forage resource availability and utilization by their domestic livestock. Given our findings, it becomes clear that the biodiversity and diversity metrics on woody, crop-related and herbaceous plant communities which are estimated from the information given by the local informants were more diverse and have wide distribution of their individuals within the study area. Close to about half of the cited forage species were perceived to be associated with upland areas as compared to the low lying localities and both habitat types combined. The majority of the cited forage species are still perceived as commonly available in the landscape. Regarding the dynamics of the abundance of these forage plants over the past few years, majority of the forage species are still believed to be increasing gradually, reflecting a health public opinion of forage plant populations status as compared to gradually decreasing and rapidly decreasing trends, as well as others; see Fig. 16) cited forage species for livestock grazing. These varying trends in changing abundance of forage species are greatly influenced by underlying ecological drivers including rainfall variability, deforestation for charcoal production and farming activities, drought and bushfires. Since local agro-pastoralists' livelihoods are heavily dependent upon natural resources availability in their communal lands, they are well aware of the need to sustainably manage their resources. This is especially true with regards to avoiding bushfires or encouraging early bushfires, stop or moderately use weedicides, application of organic manure/chemical fertilizer, crop rotation/shifting cultivation as well as pray for God's intervention to provide them with more regular rains. We, thus, recommend more LEK-related studies in other tropical and subtropical environments be conducted. The results of these studies can be highly relevant to a wider audience including researcher, policy-makers and local authorities for local biodiversity conservation practices. Further systematic research for understanding resilience and recognizing robust capacities of local inhabitants in favour of species biodiversity conservation is desirable.

7 General concluding remarks and recommendations

This research was conducted within the auspices of the West African Science Service Centre for Climate Change and Adapted Land-use (WASCAL), involving ten West African states and Germany as the sole funder, to examine how components of forage-related LEK held by local agro-pastoralists are shared and maintained across generations for sustainable rangeland management. Apart from that, this study is intended to identify forage valuation criteria from LEK holders, since human activities can be better analysed and discussed if we understand the underlying reasons behind their daily actions. Furthermore, their perceptions on forage species diversity, habitat distributions, abundance trends and ecological drivers in line with SES framework are also investigated.

To accomplish the above-referenced broad research objectives, using a multi-pronged quantitative ethnoecological approach. Methods from both natural and social sciences are employed. The research is carried out within the context of a typical Sudanian savanna in West Africa, which entails multi-cultural setting and steep climatic gradient to capture a wide range of ethnobotanical information on locally available forage resources for domestic livestock grazing in the research region. The results of this research amply demonstrate that LEK on forage resources is unevenly distributed among local agro-pastoralists. This gives credence to existing literature assertion that LEK is differentially held by local people (e.g. Briggs 2005, Ayantunde et al. 2008). These findings reflect the fact that aridity and ethnicity are important drivers of LEK accumulation and their relative importance depend on type of forage resources considered. The ethnobotanical evidence gathered in this study reveals that local agro-pastoralists belonging to different ethnic, gender and age categories in dry semi-arid and moist semi-arid exhibit lower LEK on various components of forage plants than those in dry Sub-humid and humid climatic conditions, reflecting higher floristic diversity and agro-biodiversity of useful forage species in the latter than in the former. Above all the important drivers, local climatic variability poses a major threat to LEK accumulation and ecosystem services provision (e.g. forage resources). This argument is consistent with other studies which indicate that climate (for that climate change) is the most important driver of vegetation, negatively affecting ecosystem structure and functioning in the region (Da 2010, Guuroh 2016).

Given the research findings, it is clear that a combination of varied forage sources is good for varied domestic livestock types and at different seasons. This is because local agro-pastoralists are fully aware of which type of forage plants were suitable for livestock grazing and at which seasonal regimes of the year they are experiencing. For instance, while herbaceous forage plants are most valuable in the rainy season and for cattle, woody and crop plants are most salient in the dry season, for goats and sheep for several reasons. Unlike LEK distributional patterns where both aridity and ethnicity are equally relatively important drivers, it is rather only the aridity variable which significantly influenced agro-pastoralists' citation of valuation criteria in the study countries, but not socio-demographic differences. Among all the other valuation criteria for available forage resources utilization, healthy growth of their livestock was consistently ranked as the most important underlining reason among the local agro-pastoralists. This may mean that, as long as an animal is of good health after feeding on a particular forage plant, local agro-pastoralists know that such a forage plant is very salient to them. This is because healthy animals have high productivity levels and sell at good prices on local markets. Additionally, the results of this study illustrate the extensive knowledge and understanding of local agro-pastoralists regarding cited forage species diversity and habitat distribution in the context of West Africa's savanna ecosystems. With respect to the forage abundance over the past few years, the local agro-pastoralists generally perceive cited forage plants to be gradually increasing. Nevertheless, other forage plants were also perceived to be decreasing in numbers as well. The majority of reported items (forage plants) are believed to be distributed in upland areas as compared to other topographic positions. The topmost perceived threats causing changes in the abundance trends of forage species include rainfall variability, tree cutting and drought. To effectively tackle these ecological drivers, local people themselves know of various ways toaddress them. Among various conservation measures, local agro-pastoralists suggested that they should individually and collectively stop rampant bushfires and tree and shrub cutting for charcoal production and firewood and rather begin to undertake afforestation activities to replace some already lost useful trees and shrubs in the study area.

The outlook of LEK investigations in the near future is promising, since a proper understanding of such a location- and context-specific knowledge system is vitally important for sustainable forage plants utilization and livestock production. Considering the highly unpredictable nature of the climate change and variability confronting local farmers in many parts of the globe, a profound LEK of natural resources is a prerequisite for a sustainable land management especially among resource-poor people in vulnerable dryland ecosystems. Therefore, community-based policy formulation and implementation of projects in rural communities should be of high priority to national policy-makers, scientists and civil society organizations (CSOs) to gain more local acceptance to enable implementers of future projects. This will enable them to actively utilize beneficiary rural communities' rich local knowledge for successful implementation and sustainability of such projects, like WASCAL. Thus, the findings of this LEK-oriented study are not only crucial for the West African sub-region but can also serve as a springboard elsewhere to better understand the dynamics of the global environmental change impacts on the exploitation of natural resources. This will go a long way to curb land degradation and depletion of associated ecosystem services, which commonly occur in dryland areas globally. Further research for understanding and recognizing robust capacities and resilience of local inhabitants in favour of biodiversity conservation and sustainable rural agriculture for livelihood improvement is recommended. It is also recommended that there should be narrower or more species-specific LEK study of highly useful forage species in the same studied rural communities for in-depth ethnoecological information since this current study employs a broad quantitative ethnoecological approach.

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Appendices

Appendix 1: Structured questionnaire for performance of individual ethnobotanical surveys for obtaining alternative information from local agro-pastoralists on LEK distributional patterns, valaution criteria and local perception forage species diversity in for both Ghana and Burkina Faso.

General introduction: This structured questionnaire is designed to understand, document and assess valuable ethnobotanical knowledge on available forage resources by local agro-pastoralists ('local experts') in above-mentioned West African countries. Respondents are assured that all information being gathered from them is exclusively used for academic purposes and would be treated as confidential and not used with ill intent (for local field assistants).

Section I: Demographic profile of respondents

1.1 Name of respondent (optional)				
1.2 Name of community (location)				
1.3 Age/age class (in years)				
1.4 Gender	Male	Female		
1.5 Ethnicity	Dagbani	Mossi	Gurunsi	
1.6 Educational level	No school	Primary	Secondary	Tertiary
1.7 Religion	Christian	Muslim	Traditional	Atheist
1.8 Household size				
1.9 Residential status	Native	Migrant settler	Nomadic	
1.10Date of interview (DD/MM/YYYY)				
1.11 Name of interviewer				

Section II: Implicit ranking based on free-recall of forage resources

Intro: I will write down your responses and later ask you further questions about a list of plants that you will tell me!

Q1: Please name as many as possible plants and/or crop residues which are important for feeding cattle, goats and sheep in your vicinity!	
Free list of fodder plants	Free list continues

Section III: Explicit ranking of forage resources in different seasonal types

Note: Now let us please look at the first list again!

Q2: From all these fodder plants and/ or crop residues mentioned before, which ones are important to the livestock in the rainy season? (Please rank them from most important to least important)-using the first list	
Seasonal ranking of fodder plants	Seasonal ranking continues

Q3: What criteria have you used for the above rainy season ranking of forage resources (Why?) (Please write down the answer in keywords/short sentences).	
a.	
b.	
c.	
d.	

Q4: Which of these fodder plants, in your first list, are important ones to the livestock in the dry season? (Please rank them from most important to least important)	
Seasonal ranking of fodder plants	Seasonal ranking continues
Q5: What criteria have you used for the above dry season ranking of forage resources (Why?) (Please write down the answer in keywords/short sentences).	
a.	
b.	
c.	
d.	

Section IV: Livestock preferences for forage resources (preferential ranking by locals)

Q6: Which fodder plants and/or crop residues do your cattle like to feed on? (Please rank 5 of them from highly favored/palatable to least favored/palatable)-using the first list.	
Preferential ranking of fodder plants	Preferential ranking continues
Q7: What criteria have you used for the above preferential ranking of forage resources for cattle (Why)? (Please write down the answer in keywords/short sentences)	
a.	
b.	
c.	
d.	

Q8: What do your goats like to feed on? (Please rank 5 of them from highly favored/palatable to least favored/palatable)-using the first list.	
Preferential ranking of fodder plants	Preferential ranking continues
Q9: What criteria have you used for the above preferential ranking of forage resources for goats (Why)? (Please write down the answer in keywords/short sentences)	
a.	
b.	
c.	
d.	

Q10: What kind of fodder plants and/or crop residues do your sheep also like to feed on? (Please rank 5 of them from highly favored/palatable to least favored/palatable)-using the first list.	
Preferential ranking of fodder plants	Preferential ranking continues

Q11: What criteria have you used for the above preferential ranking of forage resources for sheep (Why)? (Please write down the answer in keywords/short sentences)
a.
b.
c.
d.

Q12: What fodder plants and/or crop residues do your cattle, goats & sheep totally refuse to feed on? (Please rank 5 of them from highly favored/palatable to least favored/palatable)-using the first list.	
Preferential ranking of fodder plants	Preferential ranking continues

Q13: Why do these animals (cattle, goats & sheep) totally refuse to feed on available forage plants at all seasons? (Please write down the answer in keywords/short sentences)

a.
b.
c.
d.

Section V: Ecological parameters (habitat types and dominance/abundance of fodder plants)

i. Habitat types

Q14: Where are these above-mentioned fodder plants and/or crop residues found within your landscape?		
Lowland (L)	Highland/Upland (H)	Other habitat-please specify

ii. Dominance/abundance

Q15: What do you say about the number or population size of these preferred fodder plants and/or crop residues for your 3 livestock types (dominance/abundance)?		
Many (common)	Few (not common)	Rare or locally extinct

Section VI: Changes over time: Trends and drivers

i. Trends

Q15: What do you say about the number or population size of these preferred fodder plants and/or crop residues for your 3 livestock types (dominance/abundance)?		
Decreasing (D) trend	Increasing (I) trend	Stable (S) trend

ii. Ecological divers

Q18: What do you think are the possible causes responsible for the changing population size of these named fodder plants and/or crop residues? (Please write down the answer in keywords/short sentences)
a.
b.
c.
d.

iii. The way forward

Q18: What do you think can be done individually and collectively to handle such changes in fodder plants and/or crop residues numbers? (Please write down the answer in keywords/short sentences)
a.
b.
c.
d.

The END!

Thank you very much for your time!

Appendix 2: Specific study sites and sampling overview for LEK investigation across the delineated Climatic Zones as well as the districts or provinces in both Ghana and Burkina Faso.

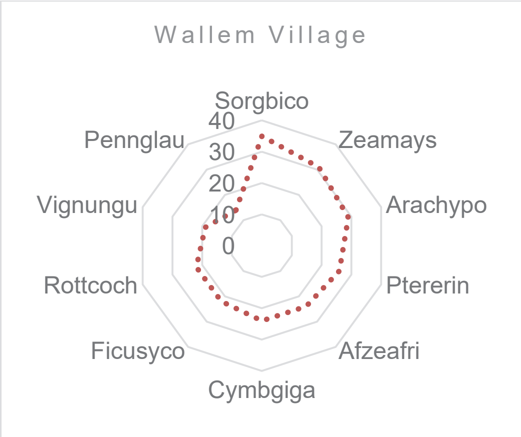
* =Own population estimates from field data in 2013. Population data obtained from GSS (2012)[1] and INDS (2006)[2].

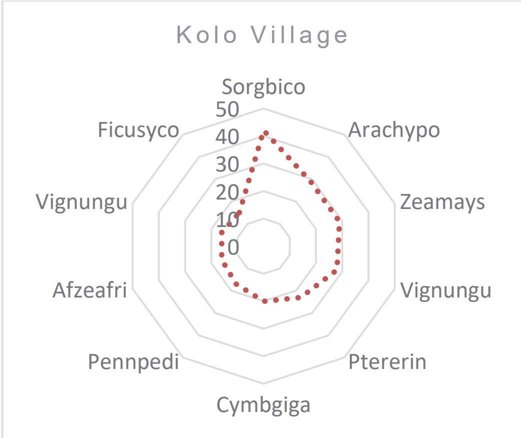
Country	Villages (sites)	District/Province	Ethnic group	Aridity class	Population	# size
Ghana	Sang	Mion	Dagbani	0.69	8,189	30
	Jegun	Savelugu-Nanton	Dagbani	0.54	654	30
	Cheko	Tamale Metroplis	Dagbani	0.55	296	30
	Nbatinga	Mion	Dagbani	0.65	1,036	30
	Kpabia	Mion	Dagbani	0.67	3,173	30
	Aniabiisi	Bolga Municipal	Gurunsi	0.44	500	30
	Nangodi	Nabdam	Gurunsi	0.48	3912	30
Burkina Faso	Wallem/Kadro	Po	Gurunsi	o.48	900*	30
	Kolo	Jaro	Gurunsi	0.50	2155	30
	Tiebele	Po	Gurunsi	0.44	54985	30
	Nobere	Manga	Mossi	0.44	3594	30
	Jegemtenga	Ouagadougou	Mossi	0.38	600*	30
	Rapadama	Ouagadougou	Mossi	0.36	2167	30
	Boore	Yaku	Mossi	0.32	1587	30
	Soubeira-Natenga	Kaya	Mossi	0.33	4542	30

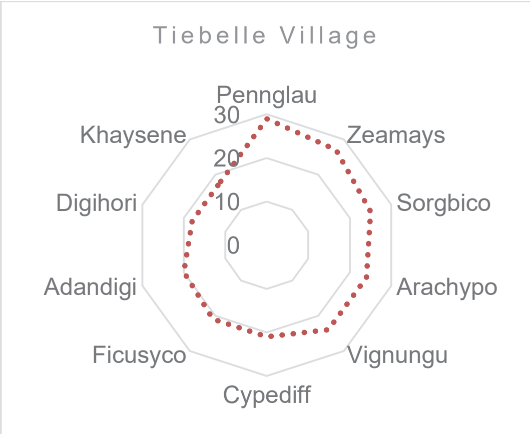
[1]GSS (2012) "2010 population and housing census. Summary report on final results." Ghana Statistical Service Report.

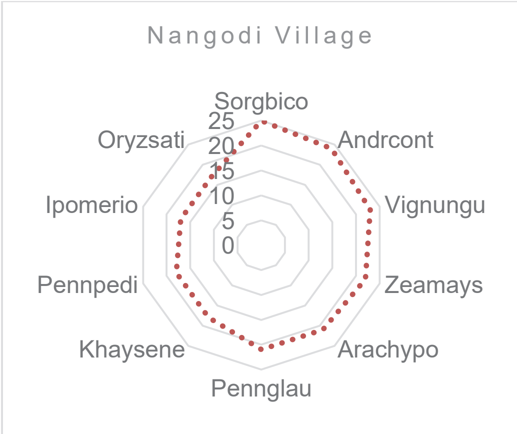
[2]INDS (2009) "Résultats préliminaires du recensement général de la population et de l'habitat de 2009, in: INSD, Direction de la Demographie, Ouagadougou, Burkina Faso, 2009." Institut National des Statistiqueset de la Demographie Ouagadougou.

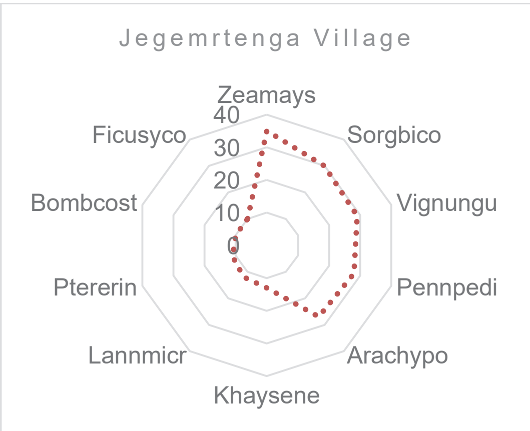
Appendix 3: Summary of the ten most dominant forage species composition given by local agro-pastoralists located in individual studied rural communities located in both Ghana and Burkina Faso.

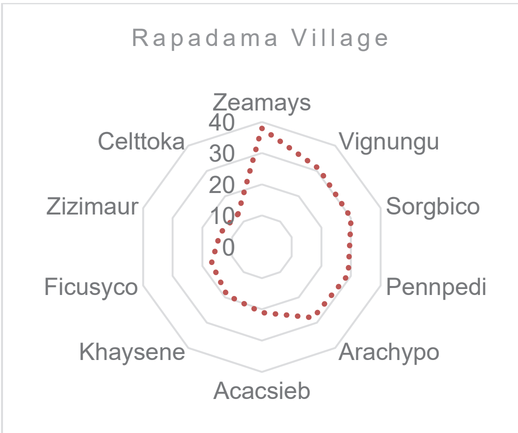

Wallem Village
Sorgbico
Zeamays
Arachypo
Ptererin
Afzeafri
Cymbgiga
Ficusyco
Rottcoch
Vignungu
Pennglau
40
30
20
10
0


Kolo Village
Sorgbico
Arachypo
Zeamays
Vignungu
Ptererin
Cymbgiga
Pennpedi
Afzeafri
Vignungu
Ficusyco
50
40
30
20
10
0


Tiebelle Village
Pennglau
Zeamays
Sorgbico
Arachypo
Vignungu
Cypediff
Ficusyco
Adandigi
Digihori
Khaysene
30
20
10
0


Nangodi Village
Sorgbico
Andrcont
Vignungu
Zeamays
Arachypo
Pennglau
Khaysene
Pennpedi
Ipomerio
Oryzsati
25
20
15
10
5
0


Jegemrtenga Village
Zeamays
Sorgbico
Vignungu
Pennpedi
Arachypo
Khaysene
Lannmicr
Ptererin
Bombcost
Ficusyco
40
30
20
10
0


Rapadama Village
Zeamays
Vignungu
Sorgbico
Pennpedi
Arachypo
Acacsieb
Khaysene
Ficusyco
Zizimaur
Celttoka
40
30
20
10
0

Note: Adandigi=*Adansonia digitata* L., Acacdudg=*Acacia dudgeonii* Craib ex Holland, Acacsieb=*Acacia sieberiana* DC., Afzeafri=*Afzelia africana* Smith ex Pers., Arachypo=*Arachis hypogaea* L., Alysrugo=*Alysicarpus rugosus* (Willd.) DC., Andrcont=*Andropogon contortus* L., Andrgaya=*Andropogon gayanus* Kunth, Bombcost=*Bombax costatum* Pellegr. & Vuill., Cajacaja=*Cajanus cajan* (L.) Millsp., Cymb.giga= *Cymbopogon giganteus* Chiov., Cypediff=*Cyperus difformis* L., Digihori=*Digitaria horizontalis* Willdenow, Dioscaye=*Dioscorea cayenensis* Lam., Eleuindi=*Eleusine indica* (L.) Gaertn, Faidalbi=*Faidherbia albida* (Del.), Ficuaspe=*Ficus aspera*, Ficusyco=*Ficus sycomorus* L., Khaysene=*Khaya senegalensis* (Desr.) A. Juss., Lannmicr=*Lannea microcarpa* Engl. & K. Krause, Loudtogo=*Loudetia togoensis* (Pilg.) C. E. Hubb., Ipomerio= *Ipomoea eriocarpa* R. Br., Maniescu=*Manihot esculenta* Crantz, Oryzsati=*Oryza sativa* L., Pennglau=*Pennisetum glaucum* L., Pennpedi=*Pennisetum pedicellatum* Trin, Ptererin=*Pterocarpus erinaceus* Lam., Rottcoch=*Rottboellia cochinchinensis* (Lour.) W. D. Clayton, Sidaacut=*Sida acuta* Burm. F., Sorgbico=*Sorghum bicolor* (L.) Moench, Vignungu=*Vigna unguiculata* (L.) Walp, Vignsubt=*Vigna subterranea* (L.) Verdc., Zeamays=*Zea mays* L. and Zizimari=*Ziziphus Mauritania* Lam.

Appendix 4A: Post hoc tests with ethnicity-based model for significant interacting effect between ethnicity and gender on LEK of herbaceous forage plant species.

Comparisons		Estimate	Std. Error	z value	p (>|z|)
2.0	1.0	0.00	0.14	0.03	1.000
3.0	1.0	-0.16	0.15	-1.07	0.874
1.1	1.0	0.53	0.07	7.29	< 0.001***
2.1	1.0	0.29	0.14	2.03	0.294
3.1	1.0	0.02	0.14	0.13	1.000
3.0	2.0	-0.16	0.15	-1.10	0.862
1.1	2.0	0.53	0.14	3.76	0.002**
2.1	2.0	0.28	0.08	3.74	0.002**
3.1	2.0	0.02	0.14	0.11	1.000
1.1	3.0	0.69	0.14	4.83	< 0.001***
2.1	3.0	0.45	0.14	3.09	0.021*
3.1	3.0	0.18	0.08	2.12	0.245
2.1	1.1	-0.24	0.14	-1.76	0.453
3.1	1.1	-0.51	0.14	-3.65	0.003**
3.1	2.1	-0.27	0.14	-1.89	0.368

Note: 1.0 = Dagbani female, 1.1 = Dagbani male, 2.0 = Gurunsi female, 2.1 = Gurunsi male, 3.0 = Mossi female, 3.1 = Mossi male.

Appendix 4B: Post hoc test with ethnicity-based model for significant interacting effect between ethnicity and gender on LEK of woody forage plant species.

Comparisons		Estimate	Std. Error	z value	p (>|z|)
2.0	1.0	-0.65	0.12	-5.23	< 0.001***
3.0	1.0	-0.47	0.12	-3.89	0.001**
1.1	1.0	-0.25	0.06	-4.22	< 0.001***
2.1	1.0	-0.52	0.12	-4.27	< 0.001***
3.1	1.0	-0.37	0.12	-3.09	0.020*
3.0	2.0	0.17	0.13	1.36	0.723
1.1	2.0	0.40	0.13	3.15	0.017*
2.1	2.0	0.12	0.07	1.66	0.522
3.1	2.0	0.27	0.13	2.16	0.227
1.1	3.0	0.22	0.12	1.80	0.425
2.1	3.0	-0.05	0.13	-0.39	0.999
3.1	3.0	0.10	0.07	1.47	0.649
2.1	1.1	-0.27	0.12	-2.19	0.215
3.1	1.1	-0.12	0.12	-1.00	0.905
3.1	2.1	0.15	0.13	1.19	0.817

Note: 1.0 = Dagbani female, 1.1 = Dagbani male, 2.0 = Gurunsi female, 2.1 = Gurunsi male, 3.0 = Mossi female, 3.1 = Mossi male.

Appendix 4C: Post hoc test with aridity-based model for significant interacting effect between aridity class and gender on total forage plant species.

Comparisons		Estimate	Std. Error	z value	p (>|z|)
2.0	1.0	0.01	0.08	0.11	1.000
3.0	1.0	0.33	0.09	3.64	0.005**
4.0	1.0	0.46	0.09	5.10	< 0.001***
1.1	1.0	0.06	0.05	1.26	0.891
2.1	1.0	0.20	0.08	2.50	0.164
3.1	1.0	0.31	0.09	3.42	0.012*
4.1	1.0	0.42	0.09	4.63	< 0.001***
3.0	2.0	0.33	0.09	3.72	0.004**
4.0	2.0	0.46	0.09	5.26	< 0.001***
1.1	2.0	0.05	0.08	0.64	0.998
2.1	2.0	0.20	0.04	4.66	< 0.001***
3.1	2.0	0.31	0.09	3.48	0.010**
4.1	2.0	0.41	0.09	4.76	< 0.001***
4.0	3.0	0.13	0.10	1.37	0.844
1.1	3.0	-0.27	0.09	-2.99	0.047*
2.1	3.0	-0.13	0.09	-1.50	0.773
3.1	3.0	-0.02	0.05	-0.40	1.000
4.1	3.0	0.09	0.10	0.93	0.979
1.1	4.0	-0.40	0.09	-4.45	< 0.001***
2.1	4.0	-0.26	0.09	-3.03	0.041*
3.1	4.0	-0.15	0.10	-1.57	0.731
4.1	4.0	-0.04	0.05	-0.92	0.980
2.1	1.1	0.14	0.08	1.76	0.597
3.1	1.1	0.25	0.09	2.76	0.087
4.1	1.1	0.36	0.09	3.97	0.002**
3.1	2.1	0.11	0.09	1.27	0.890
4.1	2.1	0.22	0.09	2.53	0.153
4.1	3.1	0.11	0.10	1.13	0.938

Note: 1.0 = Dry semiarid female, 1.1 = Dry semiarid male, 2.0 = Moist semiarid female, 2.1 = Moist semiarid male, 3.0 = Dry sub-humid female, 3.1 = Dry sub-humid male, 4.0 = Humid female and 4.1 = Humid male.

Appendix 4D: Post hoc test with aridity-based model for significant interacting effect between aridity class and gender on crop-related forage plant species.

Comparisons		Estimate	Std. Error	z value	p (>|z|)
2.0	1.0	0.10	0.08	1.18	0.936
3.0	1.0	0.45	0.09	5.28	< 0.001***
4.0	1.0	0.68	0.08	8.19	< 0.001***
1.1	1.0	-0.04	0.08	-0.42	1.000
2.1	1.0	0.20	0.08	2.41	0.232
3.1	1.0	0.32	0.09	3.57	0.009**
4.1	1.0	0.48	0.09	5.61	< 0.001***
3.0	2.0	0.35	0.08	4.47	< 0.001***
4.0	2.0	0.58	0.08	7.61	< 0.001***
1.1	2.0	-0.13	0.08	-1.61	0.745
2.1	2.0	0.10	0.07	1.40	0.858
3.1	2.0	0.22	0.08	2.65	0.136
4.1	2.0	0.38	0.08	4.83	< 0.001***
4.0	3.0	0.22	0.08	2.80	0.093
1.1	3.0	-0.49	0.09	-5.65	< 0.001***
2.1	3.0	-0.26	0.08	-3.30	0.021*
3.1	3.0	-0.13	0.08	-1.68	0.698
4.1	3.0	0.03	0.08	0.34	1.000
1.1	4.0	-0.71	0.08	-8.54	< 0.001***
2.1	4.0	-0.48	0.07	-6.46	< 0.001***
3.1	4.0	-0.36	0.08	-4.31	< 0.001**
4.1	4.0	-0.20	0.07	-2.68	0.127
2.1	1.1	0.23	0.08	2.83	0.087
3.1	1.1	0.35	0.09	3.94	0.002**
4.1	1.1	0.52	0.09	5.98	< 0.001***
3.1	2.1	0.12	0.08	1.50	0.806
4.1	2.1	0.28	0.08	3.67	0.006**
4.1	3.1	0.16	0.09	1.89	0.557

Note: 1.0 = Dry semiarid female, 1.1 = Dry semiarid male, 2.0 = Moist semiarid female, 2.1 = Moist semiarid male, 3.0 = Dry sub-humid female, 3.1 = Dry sub-humid male, 4.0 = Humid female and 4.1 = Humid male.

Appendix 4E: Post hoc test with aridity-based model for significant interacting effect between aridity class and age class on total forage plant species.

Comparisons		Estimate	Std. Error	z value	p (>|z|)
2.1	1.1	0.06	0.09	0.70	1.000
3.1	1.1	0.35	0.10	3.58	0.014*
4.1	1.1	0.48	0.10	4.98	<0.01***
1.2	1.1	-0.02	0.06	-0.27	1.000
2.2	1.1	0.15	0.09	1.71	0.828
3.2	1.1	0.37	0.10	3.83	<0.01**
4.2	1.1	0.48	0.10	4.93	<0.01***
1.3	1.1	0.10	0.06	1.70	0.832
2.3	1.1	0.12	0.09	1.31	0.969
3.3	1.1	0.24	0.10	2.42	0.337
4.3	1.1	0.36	0.10	3.72	<0.01**
3.1	2.1	0.29	0.09	3.11	0.064
4.1	2.1	0.42	0.09	4.59	<0.01***
1.2	2.1	-0.08	0.09	-0.88	0.999
2.2	2.1	0.09	0.05	1.74	0.813
3.2	2.1	0.31	0.09	3.38	0.029*
4.2	2.1	0.42	0.09	4.53	<0.01***
1.3	2.1	0.04	0.09	0.44	1.000
2.3	2.1	0.05	0.05	1.05	0.995
3.3	2.1	0.18	0.09	1.90	0.713
4.3	2.1	0.30	0.09	3.25	0.042*
4.1	3.1	0.13	0.10	1.31	0.970
1.2	3.1	-0.37	0.10	-3.73	<0.01**
2.2	3.1	-0.20	0.09	-2.17	0.517
3.2	3.1	0.02	0.06	0.41	1.000
4.2	3.1	0.13	0.10	1.26	0.977
1.3	3.1	-0.25	0.10	-2.58	0.247
2.3	3.1	-0.23	0.09	-2.53	0.275
3.3	3.1	-0.11	0.06	-1.84	0.753
4.3	3.1	0.01	0.10	0.13	1.000
1.2	4.1	-0.50	0.10	-5.12	<0.01***
2.2	4.1	-0.33	0.09	-3.64	0.012*
3.2	4.1	-0.11	0.10	-1.07	0.994
4.2	4.1	0.00	0.06	-0.08	1.000

1.3	4.1	-0.38	0.10	-3.98	<0.01**
2.3	4.1	-0.37	0.09	-4.00	<0.01**
3.3	4.1	-0.24	0.10	-2.38	0.364
4.3	4.1	-0.12	0.06	-2.09	0.570
2.2	1.2	0.17	0.09	1.89	0.720
3.2	1.2	0.39	0.10	3.98	<0.01**
4.2	1.2	0.49	0.10	5.07	<0.01***
1.3	1.2	0.12	0.06	1.96	0.671
2.3	1.2	0.13	0.09	1.49	0.925
3.3	1.2	0.26	0.10	2.58	0.248
4.3	1.2	0.38	0.10	3.86	<0.01**
3.2	2.2	0.22	0.09	2.43	0.335
4.2	2.2	0.33	0.09	3.58	0.014*
1.3	2.2	-0.05	0.09	-0.58	1.000
2.3	2.2	-0.03	0.05	-0.68	1.000
3.3	2.2	0.09	0.09	0.95	0.998
4.3	2.2	0.21	0.09	2.31	0.416
4.2	3.2	0.10	0.10	1.03	0.996
1.3	3.2	-0.27	0.10	-2.83	0.138
2.3	3.2	-0.26	0.09	-2.79	0.152
3.3	3.2	-0.13	0.06	-2.24	0.459
4.3	3.2	-0.01	0.10	-0.11	1.000
1.3	4.2	-0.38	0.10	-3.93	<0.01**
2.3	4.2	-0.36	0.09	-3.95	<0.01**
3.3	4.2	-0.24	0.10	-2.34	0.395
4.3	4.2	-0.11	0.06	-2.01	0.631
2.3	1.3	0.02	0.09	0.18	1.000
3.3	1.3	0.14	0.10	1.42	0.945
4.3	1.3	0.26	0.10	2.71	0.184
3.3	2.3	0.12	0.09	1.32	0.968
4.3	2.3	0.25	0.09	2.67	0.203
4.3	3.3	0.12	0.10	1.20	0.984

Note: 1.1 = Dry semiarid young, 1.2 = Dry semiarid middle-aged, 1.3 = Dry semiarid older adults, 2.1 = Moist semiarid young, 2.2 = Moist semiarid middle-aged, 2.3 = Moist semiarid older adults, 3.1 = Dry sub-humid young, 3.2 = Dry sub-humid middle-aged, 3.3 = Dry sub-humid older adults, 4.1 = Humid young, 4.2 = Humid middle-aged and 4.3 = Humid older adults.

Appendix 5: Post hoc tests for the climatic variable significant for explained variance in local valuation criteria for forage resources by agro-pastoralists.

A. Cri_{RS} post hoc results

Aridity comparisons	Estimate	Std. Error	z value	r	Pr(>|z|)
Moist semiarid-dry semiarid (2-1)	0.58941	0.09904	5.951	0.26	<0.001
Dry subhumid-dry semiarid (3-1)	0.82955	0.1092	7.596	0.33	<0.001
Humid-dry semiarid (4-1)	0.76199	0.11036	6.904	0.30	<0.001
Dry subhumid-moist semiarid (3-2)	0.24014	0.09622	2.496	0.11	0.060
Humid-Moist semiarid (4-2)	0.17258	0.09752	1.77	0.08	0.287
Humid-dry subhumid (4-3)	-0.0676	0.10788	-0.626	-0.03	0.923

B. Cri_{DS} post hoc results

Aridity comparisons	Estimate	Std. Error	z value	r	Pr(>|z|)
Moist semiarid-dry semiarid (2-1)	0.556507	0.087948	6.328	0.28	<0.001
Dry subhumid-dry semiarid (3-1)	0.876066	0.095434	9.18	0.40	<0.001
Humid-dry semiarid (4-1)	0.868575	0.095581	9.087	0.40	<0.001
Dry subhumid- moist semiarid (3-2)	0.319559	0.078037	4.095	0.18	<0.001
Humid-Moist semiarid (4-2)	0.312068	0.078217	3.99	0.17	<0.001
Humid-dry subhumid (4-3)	-0.00749	0.086549	-0.087	-0.004	1.000

C. Cri_{cattle} post hoc results

Aridity comparisons	Estimate	Std. Error	z value	r	Pr(>|z|)
Moist semiarid-dry semiarid (2-1)	0.58137	0.11732	4.955	0.22	<0.001
Dry subhumid-dry semiarid (3-1)	0.88214	0.13016	6.777	0.30	<0.001
Humid-dry semiarid (4-1)	0.84142	0.13073	6.436	0.28	<0.001
Dry subhumid- moist semiarid (3-2)	0.30077	0.11907	2.526	0.11	0.056
Humid-Moist semiarid (4-2)	0.26005	0.1197	2.173	0.10	0.130
Humid-dry subhumid (4-3)	-0.04072	0.13232	-0.308	-0.01	0.990

D. Cri_{goats} post hoc results

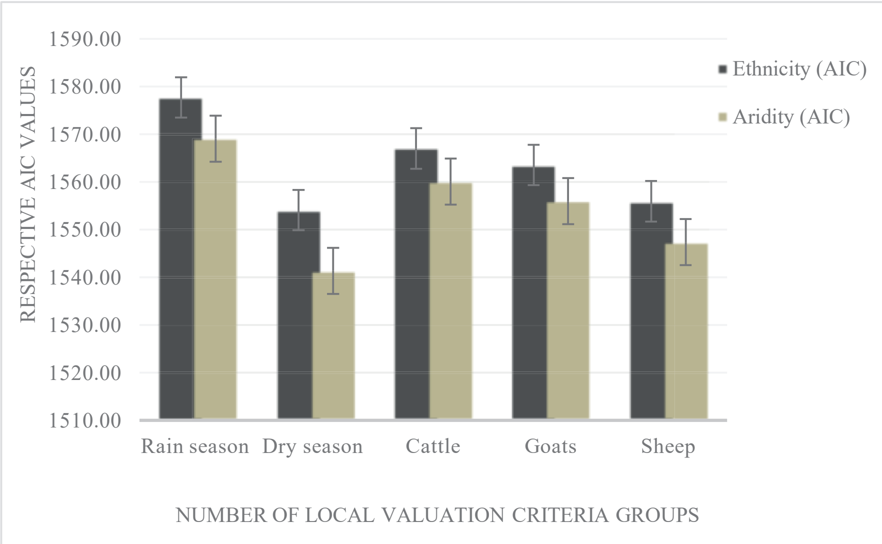
Aridity comparisons	Estimate	Std. Error	z value	r	Pr(>|z|)
Moist semiarid-dry semiarid (2-1)	0.61857	0.11325	5.462	0.24	<0.001
Dry subhumid-dry semiarid (3-1)	0.87842	0.12562	6.993	0.30	<0.001
Humid-dry semiarid (4-1)	0.85617	0.12596	6.797	0.30	<0.001
Dry subhumid- moist semiarid (3-2)	0.25985	0.11338	2.292	0.10	0.099
Humid-Moist semiarid (4-2)	0.2376	0.11374	2.089	0.10	0.156
Humid-dry subhumid (4-3)	-0.02225	0.1261	-0.176	-0.01	0.998

E. Cri_{sheep} post hoc results

Aridity comparisons	Estimate	Std. Error	z value	r	Pr(>|z|)

Moist-dry semiarid (2-1)	0.60123	0.10614	5.665	0.25	<0.001
Dry subhumid-dry semiarid (3-1)	0.91172	0.11635	7.836	0.34	<0.001
Humid-dry semiarid (4-1)	0.87036	0.11699	7.439	0.32	<0.001
Dry subhumid- moist semiarid (3-2)	0.31049	0.10292	3.017	0.13	0.013
Humid-Moist semiarid (4-2)	0.26912	0.1037	2.595	0.11	0.046
Humid-dry subhumid (4-3)	-0.04137	0.11415	-0.362	-0.02	0.984

Appendix 6: Performance of the superior aridity-based models for number of citations of local valuation crtiteria for forage resources (be it rainy and dry seasons, cattle, goats and sheep preferences as outcome variables).



Appendix 7: PCA using varimax rotation with Kaiser Normalization indicating independent variables with high loadings for various principal components for further analysis.

Variables	Component		
	1	2	3
Ethnicity of informant	**0.973**	0.036	0.021
Aridity class of a village	**0.972**	0.043	0.004
Gender of informant	-0.054	**0.778**	-0.149
Residential status	0.130	**0.741**	0.124
Age class of informant	-0.056	0.222	**0.791**
Educational background	-0.082	0.278	**-0.744**

Appendix 8: Vernacular names for cover terms used by local agro-pastoralists from different ethnic backgrounds for various forage types in the study area.

Forage types	Dagbani vernacular	Mossi vernacular	Gurunsi vernacular		
			Frafra	Kasena	Nabit
Grasse(s)	Mogu (More)	Moo (Moogu)	Muo/mooro	Gaa (Gao)	Muo(Muut)
Tree(s)	Tia (Tiihi)	Tiiga (Tiisi)	Tia/Tiisi	Teo (Teeni)	Tii(Tiih)
Crop(s)	Binderogu	Yambri (Yamdo)	Buu/Buusi	Varawudeo(-diiro)	Zoot(Zoot)

Appendix 9: Vernacular names for cover terms used by local agro-pastoralists from different ethnic backgrounds for varied livestock types in the study area.

Livestock types	Dagbani vernacular	Mossi vernacular	Gurunsi vernacular		
			Frafra	Kasena	Nabit
Cattle	Naao (Nii)	Naafu (Niini)	Naaho (Nii)	Naao(Naani)	Nao(Nigi)
Goats	Bua (Bue)	Buuga (Buusi)	Bua (Buusi)	Bugu (Bum)	Buo(Buus)
Sheep	Pegu (Peri)	Pisigu (Piisi)	Pisiku (Piisi)	Pie (Piini)	Piho(Pihi)

Appendix 10: Forage species diversity metrics for respective villages sampled in both Ghana and Burkina Faso.

No	Sampled village	SR	SE	H	SDI
1	Sang	83	0.87	3.86	0.97
2	Cheko	76	0.90	3.88	0.97
3	Jegun	71	0.88	3.76	0.97
4	Nbatinga	67	0.87	3.64	0.97
5	Kpabia	63	0.87	3.60	0.96
6	Aniabiisi	81	0.83	3.65	0.96
7	Wallem	49	0.87	3.38	0.96
8	Kolo	42	0.87	3.24	0.95
9	Tiebelle	53	0.89	3.52	0.96
10	Nangodi	44	0.89	3.38	0.96
11	Nobere	51	0.85	3.35	0.95
12	Jegemtenga	52	0.84	3.32	0.95
13	Rapadama	53	0.85	3.36	0.95
14	Sirgui	52	0.87	3.43	0.96
15	Boore	49	0.87	3.39	0.96
16	Soubeira-Natenga	53	0.90	3.58	0.97

Note: Species richness figures involve majority of forage species commonly cited in sampled villages. SR = Species richness. SE = Species evenness. H = Shannon-Wiener Diversity Index. SDI = Simpson's Diversity Index.

Appendix 11: Perceived local ecological drivers responsible for abundance trends in forage plants in the study region.

Perceived ecological drivers	CSI	Frequency (%)	Average Rank
Rainfall variability	0.375	47.30	1.89
Tree cutting/deforestation	0.276	45.20	2.53
Drought	0.250	30.80	1.67
Agricultural expansion	0.235	35.40	2.50
Bushfires	0.221	33.10	2.44
Human population increase	0.144	21.50	2.66
Soil fertility decline	0.096	16.30	2.72
Overgrazing	0.073	12.50	3.03
Reproduction of grasses and trees and crops	0.072	12.50	2.94
Natural phenomenon	0.049	7.60	2.65
Planting or protection of economic or very useful trees	0.048	9.10	3.29
Use of chemicals to spray grasses	0.042	7.80	3.49
Animal population increase	0.038	6.70	3.69
Firewood/charcoal production	0.025	5.10	3.59
Chemical fertilizer use	0.020	3.40	2.72
Continuous farming/weeding	0.019	4.00	3.14
Infrastructural development(houses)	0.015	2.90	3.27
Destruction of trees/crops by elephants &other animals	0.014	3.00	2.88
Good soils	0.013	2.10	2.82
Poverty	0.011	2.30	3.50
Destruction of plants by wind	0.011	2.10	3.36
Scarcity of farming lands	0.010	1.70	2.67
High temperatures (too much sun)	0.008	1.50	2.50
Improved understanding and exposure now to crop varieties	0.006	1.30	3.14
We dont plant more trees	0.005	0.80	2.25
Overuse of useful grasses for roofing purposes	0.005	0.80	2.25
Plants/grasses are no use to humans beings	0.004	0.80	3.75
Lack of alternative economic ventures	0.004	1.10	4.33
Establishment of forest reserve	0.004	0.80	2.50
No more many farmers interested	0.004	0.60	2.67
Grasses are naturally occurring grasses(need no planting)	0.004	0.60	2.67
Tree prunning	0.003	0.40	2.00
Weeding (some plants like weeding)	0.003	0.40	3.50
Some grasses kill others e.g. Bulaasani kills tantee	0.003	0.40	1.50

Appearance of different grass species	0.003	0.40	2.50
Despite bushfires, plants grow fast and increase in numbers	0.003	0.40	2.00
Bad methods of farming	0.003	0.40	2.00
No interest in growing some particular plants	0.002	0.60	3.67
Rocky topography	0.002	0.40	3.00
Transportation difficulties due to bad roads	0.002	0.40	5.50
Wet and dry soil types	0.002	0.40	3.00
Labour cost of bringing feeding home	0.002	0.40	4.50
Neglect of customs with tendaana (landlord)	0.002	0.40	2.00
More trees and grasses negatively affect crops growth	0.002	0.40	4.00
No freqquent bushfires	0.002	0.20	1.00
Endemic species	0.001	0.40	5.00
Farmers don’t plant more trees	0.001	0.40	4.50
Floods	0.001	0.40	6.00
Migration of other tribes like mossi, fulanis to this place	0.001	0.20	3.00
Crops needs alot of watering & buying from agric officers	0.001	0.20	4.00
Disappear when people step on it	0.001	0.20	7.00
People from town come to cut a lot of forage resources	0.000	0.40	11.00
Crop rotation	0.000	0.20	12.00
Absence of horses	0.000	0.20	4.00
Tubers are difficult to handle but dont need alot of sun	0.000	0.20	5.00
Animals feed on them much	0.000	0.20	6.00
Plant diseases-"kongsi" (leprocy)	0.000	0.20	7.00
Non-development of science	0.000	0.20	4.00
Hunger and need to earn money	0.000	0.20	8.00

Appendix 12: Local conservation measures suggested by sampled agro-pastoralists in the study region.

Local conservation measures	CSI	Frequency (%)	Average Rank
Stop bushfires	0.291	32.40	1.30
Stop cutting of trees	0.195	32.20	1.89
Afforestation	0.169	19.60	1.40
Government intervention	0.103	12.00	1.37
God's intervention	0.084	9.00	1.21
No idea	0.070	7.00	1.03
More rainfall	0.062	6.50	1.09
Maintenance of farmlands	0.058	6.30	1.21
Application of chemical fertilizer	0.050	6.90	1.75
Irrigation	0.026	3.20	1.59
Growing more crops	0.025	3.00	1.56
public education	0.022	3.20	1.88
Stop/moderate use of weedicides	0.019	2.50	1.54
Early bushfires	0.016	3.00	2.56
Fallow management/shifting cultivation	0.013	2.10	2.18
Decrease the number of animals by selling some	0.013	1.90	2.00
People should obey customs in the village	0.012	1.50	1.38
Application of organic manure	0.012	1.50	1.75
Proper storage of crop residues	0.012	1.30	1.14
Establishment of watchdog committees to fight bushfires	0.010	1.50	2.13
Balance between grazingland and cropland proportions	0.008	1.00	1.40
Crop rotational farming	0.008	0.80	1.00
Tithering of livestock in farming season	0.007	0.80	1.25
Destruction by elephants	0.005	1.00	2.20
Prunning the trees	0.005	0.60	1.33
Stop overgrazing of some grasses	0.004	0.60	1.67
Stop fulanis from migrating to our village with many cows	0.004	0.60	2.33
No solution for natural forage but for 'artificial' forage	0.004	0.40	1.00
Community assistance	0.002	0.40	2.00
Change of scattered housing setup	0.002	0.20	1.00
No clear regulation on use of lands for grazing	0.002	0.20	1.00
Chiefs intervention	0.002	0.20	1.00
Early sowing of crops	0.002	0.20	1.00
Praying for more money	0.002	0.20	1.00

Stop compound farming	0.001	0.20	3.00
Animals should be allowed to feed on grasses	0.001	0.20	2.00
Migration of strangers	0.001	0.20	3.00
Funeral performance should not be delayed	0.001	0.20	2.00
Protection of grasses and trees for livestock	0.001	0.20	2.00

Appendix 13: Summary of family richness obtained from the ethnobotanical interviews conducted in the research region.

No	Family name	Species richness	Percentage
1	Poaceae	37	19.07
2	Fabaceae	34	17.53
3	Malvaceae	11	5.67
4	Combretaceae	8	4.12
5	Rubiaceae	8	4.12
6	Cyperaceae	7	3.61
7	Euphorbiaceae	7	3.61
8	Moraceae	6	3.09
9	Amaranthaceae	5	2.58
10	Anacardiaceae	5	2.58
11	Asteraceae	4	2.06
12	Capparaceae	4	2.06
13	Meliaceae	4	2.06
14	Bombacaceae	3	1.55
15	Lamiaceae	3	1.55
16	Rutaceae	3	1.55
17	Solanaceae	3	1.55
18	Commelinaceae	2	1.03
19	Convolvulaceae	2	1.03
20	Cucurbitaceae	2	1.03
21	Musaceae	2	1.03
22	Pedaliaceae	2	1.03
23	Sterculiaceae	2	1.03
24	Verbenaceae	2	1.03
25	Acanthaceae	1	0.52
26	Aizoaceae	1	0.52
27	Annonaceae	1	0.52
28	Apocynaceae	1	0.52
29	Arecaceae	1	0.52
30	Asclepiadaceae	1	0.52
31	Balanitaceae	1	0.52
32	Bignoniaceae	1	0.52
33	Cannabaceae	1	0.52
34	Caricaceae	1	0.52

35	Celastraceae	1	0.52
36	Dioscoceaceae	1	0.52
37	Ebenaceae	1	0.52
38	Icacinaceae	1	0.52
39	Loganiaceae	1	0.52
40	Loranthaceae	1	0.52
41	Lythraceae	1	0.52
42	Moringaceae	1	0.52
43	Myrtaceae	1	0.52
44	Nyctaginaceae	1	0.52
45	Olacaceae	1	0.52
46	Opiliaceae	1	0.52
47	Polygalaceae	1	0.52
48	Rhamnaceae	1	0.52
49	Sapindaceae	1	0.52
50	Sapotaceae	1	0.52
51	Scrophulariaceae	1	0.52
52	Simaroubaceae	1	0.52
	Total	194	100.00

Appendix 14: The 19 most frequently cited forage species by local agro-pastoralists with their respect total salience values

No	Forage species	Family	FT	Parts	Dagbani vernacular	Mossi vernacular	Gurunsi vernacular	FAll(%)	FD(%)	FM (%)	FG (%)
1	*Acacia siebariana DC*	Fabaceae	Tree	Leaves, fruits	Gopieliga	Gonpeliga	Gonpeeligo(F), Sabori-pogo(K)			42	
2	*Afzelia africana smith ex pers*	Fabaceae	Tree	Leaves	Kpaliga	Kankaliga	Kolo(K), Nkpalik(N)	43.8	74.7		38.7
3	*Andropogon gayanus Kunth*	Poaceae	Grass	Aboveground	Prima	Pita/Mupoka			64.7		
4	*Arachis hypogaea L.*	Fabaceae	Crop	Leaves, residues	Singbinde/Sima	Naguri	Sikaa(F), Naguri(K), Sukpaam(N)	84.7	86	87.3	80.7
5	*Cajanus cajan (L.) Millsp*	Fabaceae	Crop	Leaves, residues	Aduwa-/Adu pogre				81.3		
6	*Eleusine indica (L.) Gaertn*	Poaceae	Grass	Aboveground	Tantee	Taraganga/Tariganga	Viisika(F), Tintugu(K), Taringban(N)	36.9			
7	*Faidherbia albida (Del)*	Fabaceae	Tree	Leaves, fruits	Puruuwooni/Pooriwooni	Zaanga	Zaanga/zaama (F), Zaanga(N)			34.7	
8	*Ficus aspera G. Forst*	Moraceae	Tree	Leaves	Ganpriga/Gampriga				70		
9	*Ficus sycomorus L.*	Moraceae	Tree	Leaves	Kenkanga/Kinkan	Kankanga	Kenkanga(F), Kapro(K), Nkang(N)	55.3	68.7	34.7	62.7
10	*Khaya senegalensis (Desr.) A. Juss*	Meliaceae	Tree	Leaves	Kugu	Kuka	Pina/Pinu(K), Kog(N)			46.7	
11	*Manihot esculenta Crantz*	Euphorbiaceae	Crop	Leaves, Peels	Banchi	Bandaku			84		
12	*Oryza sativa L.*	Poaceae	Crop	Aboveground	Sheekaafamore	Mui	Mu(F), Mumuna(K), Mui(N)				41.3
13	*Pennisetum glaucum (L.) R. Br*	Poaceae	Crop	Aboveground	Za	Naara	Naara(F), Mina/Mipona(K), Zie(N)				56
14	*Pennisetum pedicellatum Trin*	Poaceae	Grass	Aboveground	Chima	Chemugu	Kelgo (F), Yipusin(K), Kemug(N)	65.8		94.7	40.7
15	*Pterocarpus erinaceus Lam*	Fabaceae	Tree	Leaves	Nee	Nuiga	Titinga/Tintenga(K), Nolik(N)	60.7	85.3	47.3	49.3
16	*Rottboellia cochinchinensis (Lour.) W.D.C.*	Poaceae	Grass	Aboveground	Yehem/Yehim	Kalinyaanga	Morisanga(F), Manchega(K)	40.4			
17	*Sorghum bicolor (L.) Moench*	Poaceae	Crop	Leaves, residues	Chi/Defu	Baniga	Kenkan/Si(F), Baniga (K), Kazie(N)	81.8	73.3	94.7	77.3
18	*Vigna unguiculata (L.) Walp*	Fabaceae	Crop	Leaves, residues	Toa	Benga	Benkayuurisi(F), Soona(K), Tia(N)	70.7		91.3	77.3
19	*Zea mays L.*	Poaceae	Crop	Leaves, residues	Kawana	Kamaana	Karawena(F), Kamaana(K), Kareyena(N)	72.7	92	54	72

Note: FT=Forage type; FAll=Frequency for all forage species cited; FD=Frequency for only Dagbani ethnic group; FM=Frequency for only Mossi ethnic group; FG= Frequency for only Guruns ethnc group.

Appendix 15: Total forage species sampled with the study areas in northern Ghana and south-central Burkina Faso.

Scientific names	Family name	Edible parts	Plant type	Dagbani names	Mossi names	Gurunsi names		
						Frafra names	Kasena names	Nabit names
Abelmoschus esculentus (L.) Moench	Malvaceae	Leaves&fruits	C	Mana vari	Maana vaado	Magna vuuro	Pora	Mana
Acacia ataxacantha	Fabaceae	Leaves	T	x	Guaga	x	x	x
Acacia dudgeonii Craib ex Holland	Fabaceae	Leaves	T	Gozee vari/(Goozie)	Gopanyandga vaado	x	x	x
Acacia gourmaensis A Chev.	Fabaceae	Leaves	T	x	Gonsabliga	x	x	x
Acacia macrostachya Rchb. ex DC.	Fabaceae	Leaves	T	x	Zaminiga vaado	x	x	x
Acacia nilotica (L.) Willd. ex Delile	Fabaceae	Leaves	T	Bagalua/(Bagaalua)	Pegeninga biisi	Zinzirika vuuro/zinzira	x	x
Acacia senegal (L.) Willd.	Fabaceae	Leaves	T	x	Gompayadga	x	x	x
Acacia siebariana DC.	Fabaceae	Leaves	T	Gopieliga vari	Gonpeliga	Gonpeeligo vuuro	Sabori-pogo	x
Acacia spp	Fabaceae	Leaves	T	Gohe	Gumiiga	x	Sabori vooro	Gu-o vaat
Adansonia digitata L.	Bombacaceae	Fruits	T	Tuwa wuola	Tuega vaado	Toa vuuro/-wama	Tue vooro/Tew vooro	To-o vaat/wila
Afzelia africana Smith ex Pers.	Fabaceae	Leaves	T	Kpaliga vari	Kankaliga vaado	x	Kolo vooro	Nkpalik vaat
Allophylus africanus P. de Beauv.	Sapindaceae	Leaves	S	Yonaazuwa	x	x	x	x
Alternanthera pungens H.B. & K.	Amaranthaceae	Aboveground	G	Gotaba	x	x	x	x
Alysicarpus rugosus (Willd.) DC.	Fabaceae	Aboveground	G	x	Remsa	Wirikayaanga	Tigabura	Yareyang/Yarekayang
Amaranthus spinosus L.	Amaranthaceae	Aboveground	G	x	x	x	x	Lekpaluk
Amaranthus viridis L.	Amaranthaceae	Leaves	C	Aleefu	x	Aleefu	Aliefu	Aleefi
Anacardium occidentale L.	Anacardiaceae	Leaves	T	Atirinye vari	x	x	x	x
Andropogon contortis Linn.	Poaceae	Aboveground	G	Kundunpiem	x	Bangapeema/Moziebka	x	Awupeema
Andropogon fastigiatus Sw	Poaceae	Aboveground	G	Daziemam	Yampariga	x	x	
Andropogon gayanus Kunth	Poaceae	Aboveground	G	Prima	Pita/Mupoka	x	x	x
Andropogon pseudapricus Stapf	Poaceae	Aboveground	G	x	Musooliga	Kanekaa	x	Mozieg/Kalikaa
Andropogon schirensis A.Rich.	Poaceae	Aboveground	G	Zaakaloo/Saakachie	x	x	x	x
Aneilema lanceolatum Benth.	Commelinaceae	Aboveground	G	x	x	x	Waga	x
Annona senegalensis Pers.	Annonaceae	Leaves	T	Maazuule/Bulunbugu vari	x	x	Kawolo vooro	x
Anogeissus leiocarpus (DC.) Guill. & Perr.	Combretaceae	Leaves	T	Shia vari	Siiga	x	Lua vooro	x
Arachis hypogaea L.	Fabaceae	Leaves&stalk	C	Singbinde/sima vari	Naguri vaado	Sikaa vuuro	Naguri	Sukpaam vaat
Aristida kerstingii Pilger	Poaceae	Aboveground	G	x	x	x	x	Mosaalug

Ascolepis protea	Cyperaceae	Aboveground	G	Nagsaatikpira	x	x	x	x
Aspilia africana (Pers.) C.D.Adams	Asteraceae	Aboveground	G	Barangbini	x	x	x	x
Azadirachta indica A. Juss.	Meliaceae	Leaves	T	Nyimsa vari	Nima	Nimi vuuro	Plawaa	Nime vaat
Balanites aegyptiaca (L.) Del.	Balanitaceae	Leaves	T	Gingaagowu	Chegliga	Kyero	Gulisaa	x
Bauhinia rufescens Lam.	Fabaceae	Leaves	T/S	x	Bagande/Bangande	x	x	x
Boerhavia diffusa L.	Nyctaginaceae	Aboveground	G	x	x	x	Tolourou/Telero	x
Bombax buonopozense P. Beauv.	Bombacaceae	leaves	T	Vabiga vari	x	x	x	Vaaga
Bombax costatum Pellegr. & Vuill.	Bombacaceae	Leaves	T	x	Vaaga vaado	Fonka/Vonka wama/vuuro	**Gugu vooro**	x
Borassus aethiopum Mart.	Arecaceae	Leaves	T	Pukpaliga vari	x	x	x	x
Brachiaria lata (Schumach.) C.E.Hubb.	Poaceae	Aboveground	G	x	x	x	Gayara	x
Brachiaria villosa (Lam.) A.Camus	Poaceae	Aboveground	G	Gberigu	x	Saanyagri	x	Naahitaka
Bridelia ferruginea Benth.	Euphorbiaceae	Leaves	T	Ngmampoo varivari	x	x	x	x
Cadaba farinosa Forssk	Capparaceae	Leaves	T	x	Zeelugu	x	x	x
Cajanus cajan (L.) Millsp	Fabaceae	Leaves&pods	C	Aduwa- /Adu pogre	x	x	x	x
Calotropis procera (Ait.) Ait. f.	Asclepiadaceae	Leaves	T	Walapugu	x	x	x	x
Capparis corymbosa Lam.	Capparaceae	Leaves	T	x	Silkore/Shilcore/Silkere	x	x	x
Capsicum annuum L.	Solanaceae	leaves&seeds	C	Naazua vari	x	x	x	x
Carica papaya L.	Caricaceae	Leaves	C	Gonda vari	x	x	x	x
Cassia tora L.	Fabaceae	Aboveground	G	Tikpilaakum	Kati-naguri	x	Jamasooni/Jabasooni	x
Ceiba pentandra (L.) Gaertn.	Malvaceae	Leaves	T	Gunga vari	Gugu	Gonga vuuro	x	Ngong vaat/puut
Celtis toka (Forssk.) Hepper & J.R.I.Wood	Cannabaceae	Leaves	T	x	Pargamde/Paragamde	x	x	x
Citrullus lanatus (Thunb.) Matsum. & Nakai	Cucurbitaceae	Peels	C	Watermelon pogre	Pasteque vaado	x	Basteke/Pasteque	x
Citrus aurantifolia (Christm.)	Rutaceae	Leaves	T	Nyomsaa	x	x	x	x
Citrus limon (L.) Burm.f.	Rutaceae	Peels	T/S	Lemu pogre	x	x	Lemou	x
Combretum aculeatum Vent	Combretaceae	Leaves	T	x	Kulkutga	x	x	x
Combretum glutinosum Perr. ex DC.	Combretaceae	Leaves	T	Yulinga vari	Koanga/Kuanga/Kuinga	x	x	x
Combretum micranthum G.Don	Combretaceae	Leaves	T	x	Randga/Rande/Kaaninga	x	x	x
Combretum molle/Combretum collinum	Combretaceae	Leaves	T	Yukpali	x	x	x	x
Commelina benghalensis	Commelinaceae	Aboveground	G	Adomayoli/Beyolisimile/Fulunfugu	Fulunfutu	Ferikayuya	Kapulapugu	
Corchorus aestuans L.	Malvaceae	Aboveground	C	Salinvogu vari	x	x	Ayoyo	Fulat/Fuluog

Corchorus olitorius L.	Malvaceae	Aboveground	C	x	Bulvaka/Vulvaka	x	x	x
Corchorus tridens L.	Malvaceae	Aboveground	C	x	x	x	Kanyanfufuru	x
Crossopteryx febrifgga (Afzel. ex G. Don) Benth.	Rubiaceae	Leaves	T	x	x	x	Lobetie/Lobedia	x
Ctenium villosum Berhaut	Poaceae	Leaves	G	x	Bazuuri	x	x	x
Cymbopogon giganteus Chiov.	Poaceae	Aboveground	G	Mopieha/(Mopelemogu)	x	x	Guli/Gulimuo/Kasapugu	x
Cymbopogon schoenanthus (L.) Spreng.	Poaceae	Aboveground	G	Gbanzugowu	Sompiiga	x	x	x
Cynodon dactylon (L.) Pers.	Poaceae	Aboveground	G	Seuen/Suyim	x	x	x	x
Cyperus difformis L	Cyperaceae	Aboveground	G	x	Komoogu	Bombogma	Bunbugu	x
Dactyloctenium aegyptium (L.) Willd.	Poaceae	Aboveground	G	Dabolarigu	Goniga/Wande	Golgu	Konkonnataali/Konkonjataali	x
Daniella oliveri (Rolfe) Hutch. & Dalziel	Caesalpiniaceae	Leaves	T	Nyoo vari	x	x	Kacholo	x
Detarium microcarpum Guill. & Perr.	Fabaceae	leaves	T	Kpagiliga/Kpagriga	x	x	x	x
Dichrostachys glomerata (Forssk.) Chiov.	Fabaceae	Leaves	T	x	Shushudga	x	x	x
Digitaria horizontalis Willdenow	Poaceae	Aboveground	G	Kpinkpangon	Tintimteenga	Telmatian	Bangara/Mangara	Telentinge
Dioscorea cayenensis Lam.	Dioscoceaceae	Leaves&peels	C	Jelingu/Nyu pogre/Nyu vari	x	Nyubento vuuro	x	x
Diospyros mespiliformis Hochst. ex. A. DC.	Ebenaceae	Leaves	T	Doo vari	Gaaka vaado	Gian vuuro/-wama	Kekano	x
Echinochloa pyramidalis (Lam.) Hitchc. & Chase.	Poaceae	Aboveground	G	x	Kulmugu	x	x	x
Eleusine indica (L.) Gaertn.	Poaceae	Aboveground	G	Tantee	Taraganga/Tariganga	Viisika	Tintugu/Tuntogo	Taringban
Entada africana Guill. & Perr.	Fabaceae	Leaves	T	Chinchinranchiringaa/Chinchiinga	x	x	x	x
Erythrophleum africanum (Welw. ex Benth.) Harms	Fabaceae	Leaves	S	Bukponga	**x**	**x**	**x**	**x**
Euphorbia convolvuloides Hochst. ex Benth.	Euphorbiaceae	Aboveground	G	x	Youadga	x	Kunkoyele/Konkoyili	x
Faidherbia albida (Del.)	Fabaceae	Leaves&seeds	T	Puruuwooni vari/Pooriwooni vari	Zaanga	Zaanga vuuro/zaama	x	Zaanga vaat
Feretia apodanthera Delile	Rubiaceae	Leaves	T	x	Chitiga	x	x	x
Ficus aspera G.Forst.	Moraceae	Leaves	T	Ganpriga/Gampriga vari	x	x	x	x
Ficus capreifolia Delile	Moraceae	Aboveground	T	x	Kumquiga/Kulquinga vaado	x	x	x
Ficus ingens (Miq.) Miq.	Moraceae	Aboveground	T	x	Kunkuiga/Konkiega vaado	x	x	x
Ficus platyphylla Del.	Moraceae	Leaves	T	Galinzagu vari	x	x	x	x
Ficus spp	Moraceae	leaves	T	Kenkangatolinga/Kinkantolinga	x	x	Kapru-Kachegu	Nkaang-Sin-e vaat
Ficus sycomorus L.	Moraceae	Leaves	T	Kenkanga/Kinkan vari	Kankanga	Kenkanga vuuro	Kapro vooro	Nkang vaat
Fimbristylis hispidula (Vahl) Kunth	Cyperaceae	Aboveground	G	x	Soomtoega/Somtuenga	x	x	x

Gardenia ternifolia Schumach. & Thonn.	Rubiaceae	Leaves	T	Dakooga vari/Dazuli vari	Sogdra	x	x	x
Glycine max (L.) Merr.	Fabaceae	Peels	C	Salantua pogre	Suma/Suu vaado	x	Sooza	Soya beans
Gossypium hirsutum L.	Malvaceae	Leaves	C	x	Lamda/Lamna/Lamdo vaado	x	Garipogo/Garipugu/Ganton/Kanton	x
Grewia bicolor Juss.	Malvaceae	Leaves	T	Yelga vari	Yilga/Yelga vaado	x	x	x
Guiera senegalensis J.F. Gmel.	Combretaceae	Leaves	T	x	Wilinwiiga	x	x	x
Hannoa undulata (Guill. & Perr.) Planch.	Simaroubaceae	Leaves	T	Kanbaaga vari	x	x	x	x
Heteropogon contortus (L.) Beauv. ex Roem. & Schult	Poaceae	Aboveground	G	Prinkpana	x	x	x	x
Hibiscus asper Hook.f.	Malvaceae	Leaves&fruits	C	Bra vari	x	Berisi vuuro	Gaaview	Beti
Hibiscus canabinus L.	Malvaceae	Leaves&seeds	C	x	x	x	Kanzaga	x
Hibiscus sabdariffa L.	Malvaceae	Leaves&seeds	C	x	Bito/Betu vaado/kamba	Bito vuuro	Viou/View	Berehit
Hyparrhenia rufa (Nees) Stapf	Poaceae	Aboveground	G	x	x	x	Bologaa/Bolgaa	x
Icacina senegalensis A. Juss.	Icacinaceae	Leaves	S	Tankoro	x	x	x	x
Indigofera paniculata Vahl ex Pers.	Fabaceae	Aboveground	G	Mamogmakpam	x	x	x	x
Ipomoea batatas (L.) Lam.	Convolvulaceae	leaves&peels	C	Akata vari	Nanyui vaado	x	Naalugri/Naanugri	x
Ipomoea eriocarpa R. Br.	Convolvulaceae	Aboveground	G	Linlirima	Bulaamabiisi/Jinijitu	Bongabeesko	Binagsaa/Konkoli	Bonbiihi(gu)
Ischaemum afrum (J.F.Gmel.)	Poaceae	Aboveground	G	x	x	x	x	Mokerok
Isoberlinia doka Craib & Stapf	Fabaceae	Leaves	T	Kpalsuga/Kpalsugu	x	x	x	x
Khaya senegalensis (Desr.) A. Juss.	Meliaceae	Leaves	T	Kugu vari	Kuka vaado	x	Pina/Pinu vooro	Kog vaat
Kohautia senegalensis Cham. & Schltdl.	Rubiaceae	Aboveground	G	Gbielahe/Chinchindibiga	x	x	x	x
Kyllinga squamulata/Cyperus amobilis/Cyperus difformis	Cyperaceae	Aboveground	G	Nagsaatikpira	x	x	x	x
Lannea microcarpa Engl. & K.Krause	Anacardiaceae	Leaves	T	Sinsabiga vari	Sabga	Sinsaabika vuuro	**Kachugu**	Nsabk wila
Lawsonia inermis (Henna)	Lythraceae	Leaves	S	Zabila vari	x	x	x	x
Leptadenia hastata (Pers.) Decne.	Apocynaceae	Leaves	S	x	Linlinge/Lelongo	x	x	x
Loudetia togoensis (Pilg.) C.E.Hubb.	Poaceae	Aboveground	G	Pielaalum	Sudigan/Shutungu/Shutu	Pitinimuo	Chemunu/Pligaa/Plimgaa	x
Maerua crassifolia Forssk.	Capparaceae	Leaves	T	x	Chensiga	x	x	x
Mangifera indica L.	Anacardiaceae	Leaves&fruits	T	Moogo vari/Moogo pogre	Mango vaado	Monko vuuro	Mangoo vooro	Mango wila
Manihot esculenta Crantz	Euphorbiaceae	Leaves&Peels	C	Banchi vari/pogre	Bandaku	x	x	x
Maytenus senegalensis (Lam.) Exell.	Celastraceae	Leaves	T	Zegoli vari	x	x	Loo vooro	x
Melochia corchorifolia L.	Sterculiaceae	Aboveground	G	x	x	x	Bibilapugu	x
Mitragyna inermis (Wild.) O. KTZE.	Rubiaceae	Leaves	T	Shegu vari	x	x	x	x

Moringa oleifera L.	Moringaceae	Leaves&seeds	T	Moringa vari	x	Modinga	x	Moringa vaat
Musa paradisiaca L.	Musaceae	Leaves&peels	C	Kodu	x	x	x	x
Musa sapientum L.	Musaceae	Peels	C	Kodu pogre	x	x	x	x
Nauclea latifolia Smith	Rubiaceae	Leaves	T	Gulungun vari	x	x	x	Goo vaat
Opilia amentacea Roxb.	Opiliaceae	Leaves	T	x	Wag-Salgo	x	x	x
Oryza longistaminata A.Chev.&Roehr.	Poaceae	Aboveground	G	Yenyan	Kulikodire	Ngmabri	Waba/Wabi/Waaba	x
Oryza sativa L.	Poaceae	Leaves&seeds	C	Sheekaafa more/bielem	Mui Vaado	Mu vuuro	Mumuna	Mui vaat/wula
Parkia biglobosa (Jacq.) R.Br. ex G.Don	Fabaceae	Leaves	T	Doo vari	Doo vaado	Duan vuuro/-wama	x	x
Pennisetum glaucum (L.) R. Br.	Poaceae	Leaves	C	Za vari	Naara	Naara vuuro	Mina/Mipona	Zie vaat/wula
Pennisetum pedicellatum Trin.	Poaceae	Aboveground	G	Chima	Chemugu	Kelgo	Yipusin/Gapugu	Kemug
Pennisetum purpureum Schumach.	Poaceae	Aboveground	G	Kagli	Kagri	Kagri	x	x
Pericopsis laxiflora (Benth.) van Meeuwen	Fabaceae	Leaves	T	Kpiliga vari	x	x	x	x
Piliostigma reticulatum (DC.) Hochst.	Fabaceae	Fruits	T	x	Banga biisi	x	x	x
Piliostigma thonningii (SCHUM.) Milne-Redh.	Fabaceae	leaves	T	Baanga vari	x	Bangne vuuro	Vanyono	x
Prosopis africana (Guill. & Perr.) Taub.	Fabaceae	Leaves	T	Naazuli/Langin vari	x	x	x	x
Pseudocedrela kotschyi (Schweinf.) Harms	Meliaceae	Leaves	T	Sigirili vari	x	x	x	x
Psidium guajava L.	Myrtaceae	Leaves	T	Guave vari	x	x	x	x
Pterocarpus erinaceus Lam.	Fabaceae	Leaves	T	Nee vari	Nuiga vaado	x	Titinga/Tintenga voro	Nolik vaat
Pupalia lappacea (L) Juss.	Amaranthaceae	Aboveground	G	x	Nyuutabibdu	x	x	x
Rottboellia cochinchinensis (Lour.) W.D. Clayton	Poaceae	Aboveground	G	Yehem/Yehim	Kalinyaanga	Morisanga	Manchega	x
Saccharum officinarum L.	Poaceae	Leaves	C	Dakanda vari	x	x	x	x
Sapium grahamii (Stapf) Prain	Euphorbiaceae	Euphorbiaceae	G	x	x	x	x	Peehitoba
Schizachyrium sanguineum (Retz.) Alston.	Poaceae	Aboveground	G	Mopelmogu/Mupulmuo/Zaakologu	x	x	x	x
Schoenefeldia gracilis Kunth	Poaceae	Aboveground	G	x	Saaga	Poonyaangazupeeliko	x	x
Sclerocarya birrea (A.Rich.) Hochst.	Anacardiaceae	Leaves	T	x	Nobga	Dennobika vuuro	Kasolo	x
Securinega longepedunculata Fresen.	Polygalaceae	Leaves	T	x	Pelugu vaado/Kamba	x	x	x
Securinega virosa (Roxb.ex Willd.) Baill.	Euphorbiaceae	Leaves	S	Susugre vari	x	x	x	Nyaatik
Sesamum indicum L.	Pedaliaceae	Aboveground	C	x	Siili vaado	x	Nyaasanga	x
Sida acuta Burm.F.	Malvaceae	Aboveground	G	Sanbankaaniga(si)/bulaasani/naglora	Saaga	Piisika	Janbajela/Jagajila	Piirig
Solanum lycopersicum L.	Solanaceae	Leaves	C	Kamantosi vari	x	x	x	x

Solanum melongena L.	Solanaceae	Leaves&seeds	C	Ntroba/Nyadua	x	x	x	x
Sorghum bicolor (L.) Moench	Poaceae	Chaff	C	Defu/Difu(Chi)	Baniga vaado	Kenkan/Si vuuro	Yara/Kadaga/Baniga	Kazie vaat/wila
Spondias mombin Linn	Anacardiaceae	Leaves	T	Mumolitia vari	x	x	x	x
Sporobolus pyramidalis P. Beauv.	Poaceae	Aboveground	G	Sugu/Nagsaa	Gansaaga	Saasi	Naazaa	Soodmug
Sporobolus subglobosus A. Chev.	Poaceae	Aboveground	G	Sahi	x	x	x	x
Sterculia setigera Del.	Sterculiaceae	Leaves	T	Pulunpungu vari	Pomporga vaado	Pomponka vuuro	Kapolo/Kupolu/Gigiripogo	x
Stereospermum kunthianum Cham.	Bignoniaceae	Leaves	T	Zugubetia vari	Niyinga/Nayilinga	x	Ivuro	x
Strychnos spinosa Lam.	Loganiaceae	Leaves	T	Poporintia/Gingatia	x	x	Kapukura	x
Tamarindus indica L.	Leguminosae	Leaves&seeds	T	x	Pusuga	Pusika vuuro	Sana	x
Tectona grandis L.f.	Verbenaceae	Flowers	T	Aluuri pom	x	x	x	x
Tephrosia pedicellata/Indigofera hirsuta	Fabaceae	Aboveground	G	Banlari	x	x	x	x
Terminalia laxiflora Engl.	Combretaceae	Leaves	T	Koreli vari	x	x	x	x
Terminalia spp	Combretaceae	Leaves&seeds	T	x	x	x	Kogo	x
Trianthema portulacastrum linn. (bishkhapra)	Aizoaceae	Aboveground	G	Vava-ee	x	x	x	x
Trichilia emetica Vahl	Meliaceae	Leaves	T	Ngmaakpihiga vari	x	x	x	x
Vernonia cinerea (L.) Less.	Asteraceae	Aboveground	G	Naayem/Nagayem	x	x	x	x
Vetiveria nigritana (Benth.) Stapf	Poaceae	Aboveground	G	Kulikali/(Kulkarli)	x	Kulkatima	x	x
Vigna subterranea (L.) Verdc.	Fabaceae	Leaves&fruits	C	Sinkpila vari	Suma vaado	Suu vuuro	Sie	Suma
Vigna unguiculata (L.) Walp.	Fabaceae	Leaves&seeds	C	Toa- /Tu- vari/-pogr	Benga vaado	Benkayuurisi	Soona	Tia vaat
Viscum album (Linn.)	Loranthaceae	Aboveground	T	x	Welba	x	x	x
Vitellaria paradoxa C.F.Gaertn.	Sapotaceae	Leaves	T	Taanga vari	Tanga	Taanga vuuro	**Sogo vooro**	x
Vitex doniana Sweet	Verbenaceae	Leaves	T	Nganringa	Aariga vaado	Aarika wama	Kanyono	Aarik wila
Waltheria indica L.	Sterculiaceae	Aboveground	G	Budini	x	x	x	x
Ximenia americana L.	Olacaceae	Leaves	T	x	Lianga	x	Mew	x
Zea mays L.	Poaceae	Leaves&seeds	C	Kawana vari/bielem	Kamaana	Karawena vuuro	Kamaana	Kareyena vaat/wila
Ziziphus mauritiana Lam.	Rhamnaceae	Leaves	T	Zingulikukua	Mugunuga	x	x	x
Zonia glochidiata	Fabaceae	Aboveground	G	x	Natunkuli	x	x	x

Appendix 16: Unknown forage species sampled in both northern Ghana and south-central Burkina Faso.

Vernacular names	Citation frequency	Edible parts	Plant type	Habitat
Gbarigbato (D)	21	Aboveground	G	U
Koala/Kuala/Koula (K)	21	Aboveground	G/T	U/B/L
Waam (K)	11	Aboveground	G	B/L/U
Faarga/Faranga/Farangu (K)	10	Leaves	T	B/U/L
Nadoku/Nadonkuni (K)	9	Aboveground	G	B/U/L
Gigiripugu/Gigirigbugu (K)	8	Leaves	T	L/U/B
Kpaavogu vari (D)	8	Aboveground	G	B/U
Moka (M)	8	Aboveground	G	U/L
Molaa (M)	8	Aboveground	G	U/L/B
Kazono (K)	7	Leaves	T	B/U/L
Nitar (G)	6	Aboveground	G	L/B
Gunu vooro (K)	5	Leaves	T	U/L/B
Kasono vooro (K)	5	Leaves	G/T	L
Kpaazugugoli/kpaa-ingzugugoli (D)	5	Aboveground	G	U/B
Mosofi (M)	5	Aboveground	G	B/U
Nagela (K)	5	Leaves	T	U
Ngmaachi (D)	4	Aboveground	G	U/L/B
Nisisagu/Nisisugu/Nisonsongo/Nisusogu (K)	4	Leaves&seeds	G	BU/L
Pognenaaba/Puguninaaba (D)	4	Leaves	G	B/U/L
Siina (M)	4	Leaves	C	L/B
Silmiisimile/Silmisima/Similiedoo vari (D)	4	Leaves	T	U/L
Sunu vooro (K)	4	Leaves	T	B/L
Takolo/Takoli voro (K)	4	Leaves	T	U/B

Bibilapugu (K)	3	Aboveground	G	B/L/B
Chelinchegu vari/Chelinchiau (D)	3	Aboveground	G/T	U/B
Dolurugu (D)	3	Aboveground	T/G	L/L/B
Duunsimam (G)	3	Aboveground	G	U
Gampapgi (D)	3	Leaves&seeds	C	U
Kabagaa (K)	3	leaves	T/G	B/U/L
Kalkolda/Kalkundo (K)	3	Aboveground	G	L/U/B
Kuinga/Kwegega vaado (K)	3	Leaves	T	B
Kulmayogro (G)	3	Aboveground	G	L
Louanon (K)	3	Leaves&seeds	C	B
Naaze (K)	3	Leaves	G	L
Nagalega/Nagalinga (K)	3	Leaves	T	L/U
Ninta (K)	3	Aboveground	G	U/B
Pitiga (M)	3	Leaves	G	B/L
Siceli (K)	3	Aboveground	G	B/L
Sisasogo/Sisono/Sisonon (K)	3	Aboveground	G/T	B
Sizono (K)	3	Leaves	T	U/B
Suaka vari (D)	3	Leaves	T	U/B
Toholoorugu/Tolorogu(K)	3	Aboveground	G	B/L
Warsgo/Warse (K)	3	Leaves	T	U
Zinga (G)	3	Aboveground	G	L/U
Apoko (K)	2	Aboveground	T/G	L/U
Baasum (K)	2	Aboveground	G	U
Ba-inga (K)	2	Leaves	T	U/B
Barwando (K)	2	Aboveground	C/G	U
Bazuka (K)	2	Leaves	G	B/L
Binaga yili (K)	2	Aboveground	G	B/L

Bombalera/Bonbombalere (K)	2	Aboveground	G	U/B
Galinwiiga vaado (D)	2	Leaves	T	U
Ganoua/Ganonoonu (K)	2	Leaves	G	U/L
Gasungu (D)	2	Aboveground	G	B/U
Kachega (K)	2	Leaves	T	U
Kaloesaa (K)	2	Aboveground	G	L
Kama/Kama Kuuru (K)	2	Leaves&seeds	C	U/L
Kandouan (K)	2	Leaves	C	B
Kansabliga/Kaagu-Sabliga (M)	2	Leaves	T	U
Kantantue (K)	2	Leaves	T	B
Karimbanga/Karinbanga (M)	2	Leaves	T/G	B/U
Koega vaado (M)	2	Aboveground	C/T	L/B
Kuasafande (K)	2	Leaves	T	L
Kuyenka (G)	2	Leaves&seeds	T	U/L
Nagemeeli/Nagemehi (K)	2	Leaves&seeds	T	L/U
Ngilngoo (G)	2	Leaves	T	L/B
Nisasongor (K)	2	Aboveground	G	B
Paliga vari (D)	2	Leaves	T	U
Piedideli/Piedindeli (K)	2	Aboveground	T/G	U/B
Pipelssa/Pipersaa (K)	2	Leaves	T	B/L
Plingaa/Piriga/Pelinga (K)	2	Leaves	G	B/U
Pulungu/Pulunku (D)	2	Leaves	G	L
Taataabugum (D)	2	Aboveground	G	B
Titetiiga (M)	2	Leaves	T	U
Veab (G)	2	Leaves	T	U
Yibolipogon (K)	2	Aboveground	G	L
Yomaan /Yomaavaa vari (D)	2	Aboveground	G	U/B

Apaamabaani (D)	1	Aboveground	G	B
Apatia (D)	1	Leaves&seeds	C	B
Atabla vari (D)	1	Leaves	C	B
Baalanyaanga (D)	1	Leaves	S	B
Bagsanga (D)	1	Aboveground	G	L
Bajo (K)	1	Aboveground	G	B
Bamore (G)	1	Aboveground	G	L
Banayulu (K)	1	Leaves	G	B
Bancho (D)	1	Aboveground	G	B
Bandoba (K)	1	Leaves	T	B
Banlara (D)	1	Aboveground	G	B
Banzanga (K)	1	Aboveground	G	L
Barikuuga vaado (K)	1	Aboveground	T	L
Ba-uurika (G)	1	Leaves	T	U
Bayan vooro (K)	1	Aboveground	G	U
Beyali (K)	1	Leaves	C	U
Bieni-eenye (M)	1	Aboveground	G	U
Bilaaboka (K)	1	Leaves	G	B
Bina wolo (K)	1	Aboveground	G	L
Binaayolo (K)	1	Leaves	G	B
Bipano (K)	1	Aboveground	C	B
Botalgateega (G)	1	Aboveground	G	L
Boulla (K)	1	Leaves	G	L
Bresugu (K)	1	Leaves	T	B
Buganeegam (K)	1	Leaves	G	L
Bulvayaaniga (M)	1	Aboveground	T	U
Buwanga (K)	1	Aboveground	T	L

Chesawu (K)	1	Leaves	T	B
Chilinchihi (D)	1	Leaves	G	U
Chirachiga (D)	1	Leaves&seeds	T	B
Dabawere (K)	1	Leaves	C	L
Dakubeehe (M)	1	Leaves&seeds	G	U
Dankali vaat (G)	1	Leaves&seeds	C	B
Dawa (D)	1	Aboveground	G	L
Dindibile (K)	1	Aboveground	G	B
Du-ing kpagu/Dungkpagu (D)	1	Leaves	T	B
Fagam (K)	1	Aboveground	G	L
Fiiba (K)	1	Leaves	G	U
Fiou (K)	1	Leaves	C	L
Fugudugu (M)	1	Leaves	G	L
Gabona (K)	1	Aboveground	G	B
Gajega (K)	1	Aboveground	T	U
Gajoko (K)	1	Leaves	T	B
Gamgolgu vari (D)	1	Aboveground	T	U
Gangolinga vari (D)	1	Leaves	T	U
Garile vari (D)	1	Leaves	S	B
Gasinon (K)	1	Aboveground	G	L
Gayaanga (M)	1	Leaves	T	L
Gelengetiga (M)	1	Leaves	T	U
Gergendga (M)	1	Leaves	T	U
Girgindiga (M)	1	Leaves	T	U
Gobissa (K)	1	Aboveground	C	L
Gomatootesan (D)	1	Leaves&seeds	T	L
Gonyooka (M)	1	Leaves	T	U

Gooku (M)	1	Leaves&seeds	G	B
Gorgo (M)	1	Leaves	T	B
Goungor (K)	1	Leaves	T	B
Guandga (M)	1	Aboveground	G	L
Gurimatuusi (G)	1	Aboveground	G	U
Jangatiou (K)	1	Aboveground	G	U
Janpoale (K)	1	Aboveground	C	B
Jarijari (M)	1	Leaves	G	B
Kaa/Kaha (G)	1	Leaves	C	B
Kaari (G)	1	Aboveground	G	L
Kabakolo (K)	1	Aboveground	G	L
Kabeh (G)	1	Aboveground	G	U
Kabeli (K)	1	Leaves	G	U
Kabiafoulou (K)	1	Leaves	G	B
Kachelo (K)	1	Leaves	T	B
Kachugu (K)	1	Leaves	T	U
Kadi/Ruduma (K)	1	Aboveground	G	L
Kajeligugu (K)	1	Leaves	T	L
Kalechenu (K)	1	Leaves	G	B
Kalgone (K)	1	Aboveground	G	U
Kaliesaro/Kaliesaa (K)	1	Leaves	G	B
Kaligowu (K)	1	Leaves	T	U
Kaloe-jogo (K)	1	Leaves	G	B
Kaloe-Maakoga (K)	1	Leaves	G	B
Kaloiya (K)	1	Aboveground	G	U
Kalue (K)	1	Aboveground	G	L
Kamsaonga vaado (K)	1	Leaves	T	B

Kandangansile (K)	1	Leaves	G	U
Kanjalo (K)	1	Leaves	G	B
Kankavakala (K)	1	Aboveground	T	U
Kansola bie (K)	1	Leaves	T	B
Kantogu (K)	1	Leaves	T	U
Kantouan (K)	1	Leaves	C	B
Kanyaakula (K)	1	Aboveground	T	L
Kaoe-jogo (K)	1	Leaves	G	L
Kapaka (K)	1	Aboveground	G	B
Kapkilla (K)	1	Leaves	C	L
Kapolia (K)	1	Aboveground	T	U
Kapolibie (K)	1	Leaves	T	B
Kasanou (K)	1	Leaves&seeds	T	B
Kasia vooro (K)	1	Leaves	T	B
Katien (K)	1	Aboveground	C	B
Kavelanyono (K)	1	Leaves	T	B
Kavouga (K)	1	Aboveground	T	U
Kayara (K)	1	Aboveground	G	B
Kayeliguga (K)	1	Leaves	T	L
Kayibougou (K)	1	Leaves&seeds	C	B
Kengawu (K)	1	Aboveground	G	B
Kindaogo Vaado (K)	1	Aboveground	C	L
Kolaa (K)	1	Leaves	G	L
Kolkoda (K)	1	Aboveground	G	L
Kolokoodu (K)	1	Aboveground	G	L
Komponsgo (K)	1	Aboveground	T	L
Komsonogo (K)	1	Leaves	T	B

Konachuru (K)	1	Leaves&seeds	G	U
Kong (K)	1	Leaves&seeds	T	L
Korichugu (K)	1	Leaves	G	U
Koubasangan (K)	1	Aboveground	T	B
Koyem (M)	1	Leaves	T	U
Kpiimugu (D)	1	Leaves	G	U
Kpiinwagu (D)	1	Aboveground	T	U
Kuligabengdo (M)	1	Aboveground	C	L
Kulkolda (M)	1	Leaves	G	L
Kulmassa (M)	1	Leaves	T	L
Kuluga bengdo (M)	1	Aboveground	G	L
Kuma (M)	1	Leaves	C	L
Kumba vaado (M)	1	Leaves	C	L
Kusukuiga vaado (M)	1	Leaves	T	L
Lamboita pagado (M)	1	Aboveground	T	U
Lilara (K)	1	Leaves	G	L
Lorengo (M)	1	Aboveground	T	B
Luelonga vaado (M)	1	Aboveground	T	U
Mangua (K)	1	Aboveground	C	B
Manzuuri (G)	1	Leaves	C	U
Mariambariga (M)	1	Leaves	G	L
Mobio (G)	1	Aboveground	G	U
Mokarma (G)	1	Leaves	G	U
Moog (G)	1	Aboveground	G	B
Mopieha (G)	1	Leaves	G	U
Mozieli (G)	1	Aboveground	G	B
Mufawugu (G)	1	Aboveground	G	B

Naa-nakpabgbang (D)	1	Aboveground	G	B
Nabiata (M)	1	Leaves	C	U
Nachengulu (K)	1	Leaves	G	L
Nagbinde more (D)	1	leaves	C	U
Nagbinyoore guanga (M)	1	Leaves	T	U
Nagnyoore (G)	1	Leaves	G	U
Nahu (G)	1	Leaves	G	U
Najilajabila (K)	1	Leaves	G	B
Naloru (K)	1	Leaves	C	B
Naloru vooro (K)	1	Leaves	C	U
Nanchengulu (K)	1	Aboveground	G	L
Nasan vooro (K)	1	Leaves	T	B
Nasonsongo (K)	1	Leaves	G	B
Nassara dobre (M)	1	Leaves	C	B
Nazubga (M)	1	Leaves	G	L
Ngaa-gumboori (K)	1	Aboveground	T	B
Ngaboro (K)	1	Leaves	T	U
Ngmaakpiihiga (D)	1	Aboveground	T	B
Ngmazugla (D)	1	Aboveground	G	U
Niebugre (K)	1	Leaves&seeds	G	U
Niili (K)	1	Leaves	C	U
Nisesi (K)	1	Leaves	G	U
Niyea (G)	1	Aboveground	T	U
Nlon (G)	1	Leaves	T	U
Nogo (K)	1	leaves	C	B
Nuzalla (K)	1	Leaves	G	B
Nyaanire (G)	1	Aboveground	G	B

Nyaareya (G)	1	Aboveground	G	U
Nyale (G)	1	Leaves&seeds	T	U
Nyanda (G)	1	Aboveground	G	U
Nyenule (G)	1	Leaves	T	U
Ofiouho (K)	1	Aboveground	G	L
Pagbapagba (M)	1	Aboveground	T	B
Pelokoda (K)	1	Leaves	G	L
Piroloma (M)	1	Aboveground	G	U
Pitimdi (M)	1	Aboveground	G	L
Pla vooro (K)	1	leaves	T	B
Pololinyuli (M)	1	Aboveground	T	U
Pulumgon (K)	1	Aboveground	G	L
Pusongo (K)	1	Aboveground	G	L
Putuga (M)	1	Leaves	T	L
Putulmuuga vaado (M)	1	Aboveground	T	U
Qoisongo vooro (K)	1	Leaves	T	B
Raada (M)	1	Aboveground	G	L
Sankaleegsi (G)	1	Aboveground	G	U
Sanyono (K)	1	Leaves	T	U
Sawele (K)	1	Aboveground	T	U
Seela vaado (M)	1	Leaves	C	U
Seelogo (M)	1	Leaves	T	U
Shibi vari (M)	1	Leaves	T	U
Shu (M)	1	Leaves	C	L
Shumkanga (M)	1	Leaves	G	L
Sibolgo (K)	1	Aboveground	C	U
Sicesongo (K)	1	Aboveground	G	B

Sigra (M)	1	Leaves&seeds	T	U
Silesi/Sicelisi (K)	1	Aboveground	G	B
Silyaanga (M)	1	Aboveground	G	L
Singinsingo (K)	1	Leaves	G	U
Songbe (K)	1	Aboveground	G	B
Songoyoutakolo (K)	1	Aboveground	T	U
Soobee (M)	1	Aboveground	G	U
So-roingbie (K)	1	Aboveground	G	B
Souan (K)	1	Leaves	T	B
Souhan vooro (K)	1	Aboveground	T	B
Sounsoko (K)	1	Leaves	G	B
Sousonon voro (K)	1	Leaves	T	L
Suame vaat (G)	1	Leaves	C	U
Sudaada vaado (K)	1	Aboveground	C	B
Sutotiiga (M)	1	Leaves	T	U
Taabanga (M)	1	Leaves	G	B
Tagouli (K)	1	Aboveground	T	U
Talegb (G)	1	Aboveground	T	U
Tali vooro (K)	1	Leaves	T	L
Tamazaakugga (M)	1	Leaves	T	B
Tipouagabapagaba (M)	1	Aboveground	T	U
Tiritiliirihi (M)	1	Aboveground	G	U
Titue nabili (M)	1	Aboveground	G	L
Tiviru (K)	1	Leaves	T	B
Too vooro (K)	1	Leaves	T	U
Titilirihi (M)	1	Aboveground	G	U
Tunologon (K)	1	Aboveground	G	B

Vafoufolou (K)	1	Leaves	G	U
Vesongan (K)	1	Aboveground	T	B
Waampugu/Waapugu (M)	1	Aboveground	G	L
Walenaa (M)	1	Leaves	T	U
Wamtore (K)	1	Aboveground	G	L
Wangre (K)	1	Leaves	C	U
Wara (K)	1	Aboveground	C	H
Whon (K)	1	Aboveground	G	U
Womtiinga (M)	1	Aboveground	T	L
Woo (K)	1	Leaves&seeds	G	L
Wore (K)	1	Leaves	T	B
Wumure (M)	1	Leaves&seeds	G	L
Yagenkara (M)	1	Leaves	G	U
Yampala (M)	1	Aboveground	T	B
Yandga (M)	1	Leaves	G	U
Yanga (M)	1	Leaves	G	L
Yaodo (M)	1	Aboveground	T	U
Yeega/Yiiga vaado (M)	1	Leaves	T	U
Yelbulu (K)	1	Leaves	G	U
Yelgoo (M)	1	Leaves	T	B
Yepbuih (G)	1	Aboveground	G	U
Yivuru (K)	1	Leaves	T	U
Yuhimpum (G)	1	Aboveground	G	B
Yulua (K)	1	Leaves	T	H
Yurion (K)	1	Leaves	T	L
Zaaliga (M)	1	Aboveground	G	L
Zaanogula vooro (K)	1	Aboveground	G	U

Zagoraguo (D)	1	Aboveground	G	U
Zagre (G)	1	Aboveground	G	L
Zantuga (K)	1	Aboveground	T	U
Zapalemgbanna (D)	1	Aboveground	C	L
Zemu (G)	1	Leaves	G	U
Zepelikpana (D)	1	Aboveground	G	L
Ziaka (G)	1	Aboveground	G	U
Zinbrum (K)	1	Leaves	T	L
Ziniba (K)	1	Aboveground	G	L
Zitenga (K)	1	Leaves	T	L
Zoosi (G)	1	Aboveground	G	U
Zoule (K)	1	Leaves	T	B
Zounaka (K)	1	Leaves	T	B
Zuenga (K)	1	Aboveground	G	L
Zuna (K)	1	Leaves	G	L
Limprinchirenga/Limprinchirenge (D)	1	Leaves	S/G	U/B
Total	558			

Note : For vernacular names, D= Dagbani, M=Mossi and G= Gurunsi ethnic groups' vernacular names; For plant type, G=Grass, T=Tree, S=Shrub and C=Crop ; For habitat, U=Upland, L=Lowland and B=Both.

Erklärung

Ich versichere, dass ich die von mir vorgelegte Dissertation:

‘Towards an understanding and harnessing of local ecological knowledge of forage resources for sustainable rangeland management in West Africa’s Sudanian savannas’

selbstandig angefertigt, die benutzten Quellen und Hilfsmittel vollständig angegeben und die Stellen der Arbeit - einschließlich Tabellen, Karten und Abbildungen - die anderen Werken im Wortlaut oder dem Sinn nach entnommen sind, in jedem Einzelfall als Entlehnung kenntlich gemacht habe; dass diese Dissertation noch keiner anderen Fakultät oder Universität zur Prufung vorgelegen hat; dass sie - abgesehen von unten angegebenen Teilpublikationen - noch nicht veröffentlicht worden ist sowie, dass ich eine solche Veröffentlichung vor Abschluss des Promotionsverfahrens nicht vornehmen werde. Die Bestimmungen der Promotionsordnung sind mir bekannt. Die von mir vorgelegte Dissertation ist von **Prof. Dr. Boris Braun** betreut worden.

Koln, im Oktober 2016,

John-Baptist S. N. Naah, M.Sc.

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- 2002-2006: BSc degree in Natural Resources Management (Wildlife and Range Management), Kwame Nkrumah University of Science and Technology (KNUST), Ghana

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- Three-day reintegration workshop in Bonn on 'Getting prepared'-Returning home and integrating into your country's labor market. World University Service (WUS), Goebenstraße 35, 65195 Wiesbaden. Seminar leader: Dr. Julia Boger, 27th-29th May, 2016
- Training in Microsoft Access 2013 application (Datenbankentwicklung mit Microsoft Access 2013) at the University of Cologne, Regionales Rechenzentrum (RRZK), Weyertal 121, 50931 Köln. Referent: Kervin Kaatz, 12th September, 2014
- Training in statistics with R software (Kurs für Ein-UmsteigeR) at the University of Cologne, Regionales Rechenzentrum (RRZK), Weyertal 121, 50931 Köln. Referent: Dipl.-Psych. Frederik Aust, 18th August, 2014
- Training in advanced IBM SPSS course (IBM SPSS Fortgeschrittene Kurs) at the University of Cologne, Regionales Rechenzentrum (RRZK), Weyertal 121, 50931 Köln. Referent: Dr. Roscoe Araujo, 5th August, 2014
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SCHOLARSHIPS, GRANTS AND AWARDS:

- 2016: Travel grant by AGRINATURA for Tropentag conference in Vienna, Austria
- 2012-2016: Scholarship for doctoral studies by Bundesministerium für Bildung und Forschung (BMBF), Germany

- 2011: Award of certificate of participation as a UN Volunteer for 64th Annual UN-DPI/NGO conference, city of Bonn, Germany
- 2009-2011: DAAD Scholarship for MSc studies at Cologne University of Applied Sciences, Germany
- 2007: Earthwatch Fellowship for young scientists interested in Conservation Biology in Brong-Ahafo region of Ghana, given by Earthwatch Institute, United Kingdom

PUBLICATIONS (PEER-REVIEWED ARTICLES):

- **Naah J. S. N**. & J. Hamhaber, 2015. Lighting up the villages: Livelihood impacts of decentralized stand-alone solar photovoltaic electrification in rural northern Ghana Journal of Natural Resources and Development 5:1-13. http://jnrd.info/2015/01/10-5027jnrd-v5i0-01/
- **Naah J. S. N.** 2015. Evaluating impacts of distributed solar home systems in rural communities: Lessons learnt from Ghana Energy Development and Access Project in the Upper West Region of Ghana. The Journal of Energy and Natural Resource Management, 4th issue. http://uenr.edu.gh/jenrm/fourth-issue-jenrm-vol-1-2015/

MEDIA PUBLICATIONS (NON PEER-REVIEW):

- **Naah**, **J. S. N.**, 2015. 'Dumsor' crisis in Ghana: A good eye-opener for intensification of future renewable energy technologies, 5th May 2015 Website: http://www.myjoyonline.com/opinion/2015/May-5th/-dumsor-crisis-in ghana-a-good-eye-opener-for-intensification-of-future-renewables
- **Naah**, **J. S. N.**, 2013. Renewable energy and nuclear energy in Ghana, 16th April 2013 Website: http://opinion.myjoyonline.com/pages/feature/201304/104560.php

CONFERENCE PROCEEDINGS:

- **Naah, J. S. N.**, 2016. How do local agro-pastoralists judge their forage resources? Using quantitative ethnoecological approach in West Africa. Tropentag conference, Vienna, Austria, 18th – 21st September 2016 [Poster presentation]
- **Naah, J. S. N.**, 2016. Determinants of agro-pastoralists' valuation criteria of forage resources in West Africa's Sudanian savannas-an ethnobotanical approach. 46th Anniversary Conference of the Ecological Society of Germany, Austria and

Switzerland (GfÖ), Marburg, Germany, 05th – 09th September 2016 [Oral presentation]

- **Naah, J. S. N.**, I. Eguavoen, R. T. Guuroh, A. Linstädter, 2015. Distributional patterns of local ecological knowledge on forage plants: Insights from local agro-pastoralists in West Africa. 45th Anniversary Conference of the Ecological Society of Germany, Austria and Switzerland (GfÖ), Göttingen, Germany, 31th August – 04th September 2015 [Poster presentation]

INVITED GUEST LECTURE:

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COMPUTER SOFTWARE SKILLS:

- SPSS (proficient user)
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(Date: 10th October, 2016)