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Giraffe foraging ecology in the Tarangire Manyara ecosystem, Tanzania

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GIRAFFE FORAGING ECOLOGY IN THE TARANGIRE MANYARA ECOSYSTEM, TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Management of rangelands requires knowledge of forage species that are preferred or avoided by wildlife and livestock. The recent and rapid transformation of habitat by humans has led to increased concerns about the proper management of rangelands. In East African savanna ecosystems, the expansion of woody vegetation into previously open grasslands has led some rangeland managers to advocate for the active removal of native bushes to maintain grazing lawns in African savanna ecosystems. However, little is known about how browsing herbivores might benefit from the ingrowth of woody vegetation. Diet selection by the Masai giraffe (*Giraffa camelopardalis tippelskirchi*) was quantified in the Tarangire Manyara Ecosystem of Tanzania. Instantaneous scan sampling was used to quantify foraged woody plant species and compare those data with proportions of available woody plant species at two different spatial scales during a wet and dry season and between areas of different protection statuses. Study results showed that giraffes demonstrated strong selection towards some woody plant species while avoiding others, both at the local and the landscape scale. Giraffes preferentially used more forage species in less protected areas (8 forage species) than in a fully protected area (only 1 species). At both spatial scales, giraffes significantly preferred the shrub *Dichrostachys cinerea*, a species that livestock managers have classified as encroacher species needing removal. This preference was visible in the wet and dry seasons. The results of this study suggest that browsing wildlife species such as giraffes may be adversely affected by the removal of *D. cinerea* from rangelands and that managing for grazing livestock only could negatively impact browsing wildlife on mixed-use lands.

Keywords: rangeland ecology, resource selection, savanna landscapes, Tanzania, eastern Africa, browser, woody vegetation

DECLARATION

I, Matana Levi, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

02/07/2022

Matana Levi — Date

Name and Signature of the candidate

The above declaration is confirmed

23/06/22

Prof. Anna C. Treydte — Date

Name and Signature of Supervisor

03/07/2022

Prof. Derek E. Lee — Date

Name and Signature of Supervisor

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CERTIFICATION

The undersigned certify that they have read the dissertation titled "Giraffe Foraging Ecology in Tarangire Manyara Ecosystem, Tanzania" to be accepted in fulfillment of the requirements for the degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

I want to dedicate this work to my beloved Mother, Monica, her love and prayers are the ultimate keys to my life goals and success. I also dedicate this work to my mentors, Prof. Anna Christina Treydte and Prof. Derek Edward Lee, for their thoughtfulness, guidance, and support they tirelessly offered to make this work reality. Their experiences in resource assessment and savannah ungulate ecology instilled me with the ability to materialize a barrage of scientific concepts I only imagined. I find no way good enough to thank them for their diligent mentorship, but I will forever be grateful.

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LIST OF ABBREVIATIONS AND SYMBOLS

TME: Tarangire Manyara Ecosystem

TNP: Tarangire National Park

NP: National Park

WMA: Wildlife Management Area

RWMA: Randilen WMA

MR: Manyara Ranch

IUCN: International Union for conservation of nature

Km: Kilometer

M: Metre

masl: Metres above sea level

NM-AIST: Nelson Mandela African Institution of Science and Technology

TAWIRI: Tanzania Wildlife Research Institute

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Understanding animal resource selection has been a cornerstone of basic ecology and rangeland management for decades (Pellew, 1983; Mahenya *et al.,* 2016b). Resource selection studies provide empirical evidence about feeding ecology and habitat suitability, which can inform animal conservation (Pellew, 1984b; Arthur *et al.,* 1996; Manly *et al.,* 2002; Bryson-Morrison *et al.,* 2017). The pace of habitat transformation and human resource utilization have led to increased concern for the proper management of rangelands (Belayneh & Tessema, 2017; Birhane *et al.,* 2017; Devine *et al.,* 2017). In African savannas, this transformation is often expressed as an expansion of woody vegetation into open grass-dominated lands, highlighting the importance of assessing animal forage selection (Hudak & Wessman, 1998; Van de Vijver *et al.,* 1999; Ludwig, 2001; Roques *et al.,* 2001; Ludwig *et al.,* 2008; Zimmermann *et al.,* 2009; Devine *et al.,* 2017). Details on the causes of woody expansion in savanna landscapes are complex. Savannas are a heterogeneous mosaic of grass and woody plant-dominated patches, where the woody plant or grass dominance is determined primarily by precipitation and soil nutrients with strong mediating effects from fire frequency and severity, carbon dioxide concentrations, herbivore density and distribution (Higgins *et al.,* 2000; Guidão *et al.,* 2002; Sankaran *et al.,* 2005; Sankaran *et al.,* 2008). Savannas support the highest densities of wild mammalian herbivores of any biome (Grady & Hoffmann, 2012), and thus understanding how herbivores select food resources is critical for maintaining ecosystem function and conserving biodiversity.

Changes in the structure and composition of vegetation cover can impact the feeding ecology of herbivores in African savanna ecosystems (Ludwig, 2001; Linderman, 2005; Ben-Shahar, 2007; Zarovali *et al.,* 2007; Belayneh & Tessema, 2017; Devine *et al.,* 2017). While giraffe populations are mostly restricted to protected areas with either strictly or less protection status (Muller *et al*., 2016), the hastened expansion of woody plants in areas with high grazing pressure might have impacted giraffe forage ecology adversely (Kiffner *et al.,* 2017; Njagi, 2019). Some studies have shown that an influx of woody plants into previously grass-dominated savanna ecosystems could result in lower livestock production and herbaceous community degradation (Hobbs & Mooney, 1986; Kangalawe, 2009; Ratajczak *et al.,* 2012). The occurrence in previously grass-dominated rangelands of fast-spreading shrubs such as *Dichrostachys cinerea,* a native species that tend to form clonal mats in areas heavily impacted by domestic livestock grazing (Tjelele *et al.*, 2014), has led some to believe active management is needed to maintain grazing lawns for wildlife and livestock (Kiffner *et al.*, 2017; Njagi, 2019). Most studies have approached grass-dominated to woody-dominated vegetation dynamics from the perspective of grazing animals, but little is known about whether browsing species such as giraffe (*Giraffa camelopardalis tippelskirchi*) might benefit from the expansion of shrubs such as *D. cinerea*.

Forage resource selection is defined as the ratio of proportional use over proportional availability for a given forage plant species or taxa (Johnson, 1980b; Manly *et al.,* 2002; Dumont *et al.,* 2007). Animals presumably select forage resources with the best available quality to meet their nutritional requirements (Pellew, 1984a; Mahenya *et al.,* 2016a; Mahenya *et al.,* 2016b). Selection is referred to as "preference" if use is greater than availability and "avoidance" when usage is less than availability (Johnson, 1980). The selection of forage resources occurs on different spatial scales ranging from an entire geographic area (landscape) exploited by a species to the selection of forage items within foraging patches (Johnson, 1980b; Johnson *et al.,* 2002; Boyce, 2006; Owen, 2014). These spatial scales affect the proportions of available forage resource estimates and, consequently, resource selection (Bissonette *et al.*, 1997). Thus, the inferences made during resource selection studies must take into account the spatial scale of selection (Johnson, 1980; Wiens, 1981; Orians & Wittenberger, 1991; Manly *et al.*, 2002). Decisions by a researcher regarding the spatial scale that should be addressed to estimate used versus available proportions largely depend on the nature and the scope of the study (Johnson, 1980a; Manly *et al.,* 2002; Boyce, 2006). However, using only one spatial scale of resource assessment, especially in heterogeneous landscapes like east African savanna woodlands, is potentially insufficient and may not be enough for informed rangeland management decisions (Wiens, 1981; Arthur *et al.,* 1996; Kotliar & Wiens, 2013). Hence this study applies local and landscape spatial scale analysis to explore animals' hierarchical mode of acquiring woody forage resources, thus providing comprehensive baseline information on the current used-available resources in savanna landscape.

1.2 Statement of the Problem

In many African savanna landscapes, there has been a progressive replacement of open savanna grassland with shrubs, a phenomenon that modifies the structure and composition of the vegetation (Belayneh & Tessema, 2017; Devine *et al.,* 2017; Kiffner *et al.,* 2017). Despite a general increase in woody vegetation in rangeland systems (Belayneh & Tessema, 2017), which should have benefitted browser species (Pellew, 1984b; Mahenya *et al.,* 2016a), giraffe numbers have declined by 49-51% within the last three decades (Kiffner *et al.,* 2017; Bolger *et al.,* 2019). Changes in the structure and composition of vegetation cover can impact the feeding ecology of herbivores in mosaic savanna ecosystems (Ludwig, 2001; Linderman, 2005; Ben-Shahar, 2007; Zarovali *et al.,* 2007; Belayneh & Tessema, 2017; Devine *et al*., 2017). For example, an influx of woody plants into grass-dominated savanna ecosystems degrades the quality of rangelands, thus adversely affecting livestock production (Hobbs & Mooney, 1986; Kangalawe, 2009; Ratajczak *et al.,* 2012). The expansion of shrubs such as *Dichrostachys* species on grass-dominated rangelands degrades the quality of grazing lawns used by wildlife and livestock and consequently affects the livelihoods of pastoral communities (Oba *et al.,* 2000). Most studies have approached grass-dominated to woody-dominated vegetation dynamics from the perspective of grazing animals (Dalle *et al.,* 2006; Smit & Prins, 2015), but little is known about whether browsing species such as giraffes might benefit from the spread of bushes such as *Dichrostachys cinerea*.

In this study, the diet and forage selection by Masai giraffes were examined at local and landscape scales, specifically their use of woody plant species in relation to their availability. The study also compared giraffe forage selection in three protected areas with different protection statuses to understand giraffe herd distribution and resource selection under varying protection statuses. The study further investigated whether the spread of woody plants might benefit giraffe feeding ecology by providing preferred forage or adversely affect the feeding ecology due to the expansion of unpalatable species.

1.3 Rationale of the Study

This study examined whether giraffe foraging behavior at different spatio-temporal scales is affected proportionally by forage species availability. The results of this study will provide rangeland managers with comprehensive baseline information on the current availability and usability of woody forage species in the Tarangire Manyara Ecosystem of Tanzania. Information presented in this study will be useful for monitoring natural and human-influenced habitat changes for sustainable biodiversity conservation.

1.4 Objectives

1.4.1 Main Objectives

To determine the forage availability and feeding behavior of Masai giraffes at local and landscape scales in the Tarangire Manyara ecosystem, with particular attention to *Dichrostachys cinerea*, a shrub species that tend to form clonal mats in areas heavily impacted by domestic livestock grazing.

1.4.2 Specific Objectives

i. To quantify the local and landscape forage selection by giraffes in the core part of the Tarangire Manyara Ecosystem
ii. To determine the seasonal forage selection and foraging preferences of giraffes in a large heterogeneous landscape
iii. To quantify the potential importance of *D. cinerea* as a forage species in the core part of the Tarangire Manyara Ecosystem
iv. To determine the seasonal forage selection and foraging preferences of giraffes in areas with different protection status

1.5 Research Questions

i. What woody plant species do giraffes feed on in the Tarangire Manyara Ecosystem?
ii. Is the use of forage species random or selective?
iii. If giraffes are selective, which plant species are preferred or avoided?
iv. How does giraffe forage selection differ with regard to spatial scales and seasonal differences?
v. How does giraffe forage selection differ with regard to the protection status of the habitat?

The study predicted that giraffes would be selective in their foraging, as demonstrated in previous studies in other ecosystems (Sauer *et al.,* 1977; Caister *et al.,* 2003; Parker *et al.,* 2003) and that foraging selection would change according to spatial scale (Bissonette *et al.,* 1997) and season (Sauer *et al.,* 1977; Berry & Bercovitch, 2016). The study also predicted that giraffes would avoid browsing on *D. cinerea*, a shrub that is believed to be unpalatable to large mammalian herbivores. The study predicted that local scale forage selection would be less evident than the selection at the landscape scale because, while foraging, giraffes would have already chosen to be in locations with their preferred food sources (Bissonette *et al.,* 1997; Anderson *et al.,* 2005). It was also predicted that giraffe forage selection would be highly evident in fully protected areas (e.g. Tarangire National Park) versus less protected areas (e.g. Manyara Ranch and Randilen WMA) because human activities such as overstocking might have reduced forage resources for giraffes (Bryson-Morrison *et al*., 2017). The study further predicted that the giraffe diet would be composed of fewer plant species in the dry season than in the wet season because the drought-deciduous species would be less available as forage during the dry season (Berry & Bercovitch, 2016; Parker & Bernard, 2005). The generic name, *Vachellia*, was used in place of the former genus *Acacia* for Africa and Asia as agreed by the Nomenclature Session of the Seventeenth International Botanical Congress (IBC) in 2003 (Maslin, 2008).

1.6 Significance of the Study

The giraffe is Tanzania's iconic species and one of the four mega-herbivore species that occur in Tanzania (Bolger *et al.,* 2019). Despite its local importance to the country's eco-tourism economy, little is known about giraffe use, preference, or avoidance of different woody plant species, particularly *D. cinerea*, a shrub that has recently increased in many African savanna ecosystems (Roques *et al.,* 2001; Smith *et al.,* 2005; Mudzengi *et al.,* 2014; Tjelele *et al.,* 2014). The proposed study will provide information about the current availability and utilization of primary woody plant browse species in the Tarangire Manyara ecosystem, and their use by giraffes. Results obtained from this study will inform rangeland management practices for effective giraffe conservation.

1.7 Delineation of the Study

This study examined the diet and forage selection by Masai giraffes at two different spatial scales (local and landscape scales) during the wet and dry seasons. The study specifically assessed the use of woody plant species in relation to their availability by giraffes in the Tarangire Manyara Ecosystem of Tanzania. The study also compared giraffe forage selection across three areas with different protection statuses to understand giraffe herd distribution and resource selection under varying protection statuses. This study used a multispectral scaled analysis for understanding the forage-procuring strategies of giraffes. These analyses provide a reliable means of comparing use versus availability estimates of various plant species at local and landscape scales, which can help management decisions of giraffe populations in the Tarangire Manyara Ecosystem.

CHAPTER TWO

LITERATURE REVIEW

2.1 Giraffe Populations and Woody Vegetation Dynamics

The Masai giraffe is an endangered mega-herbivore inhabiting African savannas (Brand, 2007; Bolger *et al.*, 2019). Despite their narrow range across East Africa (Bolger *et al.*, 2019), little is known about their feeding ecology in human-influenced landscapes. Woody vegetation dynamics have been related to giraffe population declines (Strauss *et al.*, 2015; Muller *et al.*, 2016). Despite a general increase in woody vegetation across rangeland systems (Belayneh & Tessema, 2017), giraffe numbers have declined by 49-51% within the last three decades (Bolger *et al.*, 2019). The commonly reported causes of such decline include land use and habitat changes, climate change, human activities (e.g. overgrazing, bush fires, illegal hunting), and invasive species (Zarovali *et al.*, 2007; Belayneh & Tessema, 2017; Bolger *et al.*, 2019). Some studies have shown that an influx of woody plants into previously grass-dominated savanna ecosystems could result in lower livestock production and herbaceous community degradation (Hobbs & Mooney, 1986; Kangalawe, 2009; Ratajczak *et al.*, 2012). Feeding ecology and foraging selection of giraffes are strongly impacted by these dynamics as documented for a few giraffe populations (Pellew, 1984b; Shorrocks, 2015; Mahenya *et al.*, 2016a). However, little is known with regard to foraging resource selection by giraffes in human-influenced landscapes such as the Tarangire Manyara Ecosystem in northern Tanzania.

2.2 Diet Composition and Forage Selection

Giraffes forage on a variety of woody plant species but concentrate on a narrow range of forage options most of which are *Vachellia* species (Pellew, 1983; Lamprey, 1964; Voeten & Prins, 1999; Parker *et al.*, 2003; Parker & Bernard, 2005; Mahenya *et al.*, 2016a; Muller *et al.*, 2016). Preferential use of forage resources by giraffes is mainly determined by the availability of quality forage resources (Pellew, 1983, 1984b; Caister *et al*., 2003; Mahenya *et al.*, 2016a; Mahenya *et al.*, 2016b). Masai giraffe's forage selection and feeding ecology in savanna habitats are documented in a few previous studies (Pellew, 1983; Main, 1998; Caister *et al.*, 2003; Dagg, 2015; Mahenya *et al.*, 2016). Forage species most commonly used by giraffes in East African savannas *include Vachellia spp., Commiphora spp*., and Com*bretum spp*. (Lamprey, 1964;

Pellew, 1983, 1984b; Mahenya *et al.*, 2016a). However, forage resource availability and their use by giraffes in East African savanna landscapes have not been quantified. Likewise, it is still unknown if the spread of encroaching species like *Dichrostachys cinerea* has substantially benefitted browsers (giraffes) or whether they lower forage availability for other species in the Tarangire Manyara Ecosystem.

Previous studies reported that giraffes exhibit seasonal forage selection toward some plant species, with deciduous plants being favored during the wet season (Sauer *et al.*, 1977; Sauer, 1983; Pellew, 1984b; Parker *et al.*, 2003). However, during the dry season, deciduous plants shed their leaves resulting in a decrease of deciduous plant availability thus affecting giraffe forage selection behavior (Hall-Martin & Basson, 1974; Sauer *et al.*, 1977; Sauer, 1983; Pellew, 1984a). For example, *Vachellia tortilis* was shown to be the most consumed species in the Serengeti National Park during the wet season, but *Grewia species* became the most foraged plants during the dry season (Pellew, 1984a). Hall-Martin (1974) reported that the bulk of the giraffe diet in Timbavati Private Nature Reserve in South Africa was comprised of *Vachellia nigrescens* in the wet season but switched to *Colophospermum mopane*, *Gymnosporia senegalensis*, and *Euclea undulata* with the course of the dry season. Field and Ross (1976) found that *Vachellia gerrardi* and *Balanites aegyptica* were the most favored species in Kidepo Valley National Park, Uganda, during the dry season but giraffe concentrated on *Gymnosporia senegalensis* and *Zizyphus abyssinica* during the wet season. This study investigated how giraffe forage selection differs seasonally and across two different spatial scales (local and landscape scales) in the Tarangire Manyara Ecosystem, northern Tanzania.

2.3 Forage Selection and Protection Status

Masai giraffes inhabit both strictly and less protected areas (Msoffe *et al.*, 2011; Kiffner *et al.*, 2017; Bolger *et al.*, 2019). Human-driven habitat changes affect the availability of forage resources for giraffes, particularly in areas with relatively low protection status (Kiffner *et al.*, 2017; Njagi, 2019). Intensified human resource exploitation in less protected areas might result in the loss of plant species (Köster *et al.*, 2013), limiting the available forage resources for giraffes. Changes in the qualities and quantities of forages greatly affect the patterns of forage use, reproduction, growth, and the general viability of giraffe populations (Hall-Martin &

Basson, 1974; Sauer *et al.,* 1977; Sauer, 1983, Caister *et al.,* 2003). But little is known with regard to foraging behavior and habitat selection by giraffes in areas with different protection statuses.

Tarangire Manyara Ecosystem (TME), is comprised of areas with strictly protection status (e.g. Tarangire National Park), as well as areas with less protection status (e.g. Manyara Ranch and Randilen Wildlife Management Area) (Ludwig, 2001; Duran, 2015). Tarangire Manyara Ecosystem was reported to have been experiencing habitat changes inflicted by increased human populations (Msoffe *et al.,* 2011; Kiffner *et al.,* 2017). Further, habitat fragmentation and reduction of connectivity threaten the area mainly due to agricultural activities and livestock keeping (Caro *et al.,* 2009; Msoffe *et al.,* 2011). Thus, there is a need to ensure that the quality and quantity of forage resources are available for giraffes and other wildlife species. The proposed study seeks to understand forage species availability in areas with varying protection statuses, and how this affects food selection by giraffes in the TME.

2.4 Spatial Scales and Forage Resource Use

Forage resource selection occurs across different spatial scales ranging from an entire geographic area (landscape) to the selection of forage items within foraging patches (Boyce, 2006; Manly *et al.,* 2002). Changes in spatial scales affect estimated proportions of available forage resources and consequently animal resource use versus availability decisions (Bissonette *et al.,* 1997). The choice of an appropriate spatial scale for resource used-available proportion estimates largely depends on the nature and the scope of the study (Johnson, 1980; Boyce, 2006; Manly *et al.,* 2002). However, a multispectral scaled analysis accounting for essential ecological processes occurring at different spatial scales provides a reliable means of comparing use versus available estimates, especially in large heterogeneous landscapes (Wiens, 1981; Arthur *et al.,* 1996). Hence, this study applied multispectral scaled analyses (i.e. local and landscape scales) to compare giraffe forage selection in both wet and dry seasons.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

This study was carried out in the core part of the Tarangire Manyara Ecosystem (TME), northern Tanzania, in three protected areas: Tarangire National Park (TNP), which is strictly protected, Manyara Ranch (M.R.), which allows ranching and wildlife tourism and the Randilen Wildlife Management Area (RWMA), a community-based conservation area (Fig. 1). In TNP, only game viewing and research are allowed (Ludwig, 2001), while RWMA uses a participatory approach that directly benefits the community aiming to protect the needs of local pastoral communities and conserve wildlife (Duran, 2015). The TME receives an annual rainfall of 434 mm to 1003 mm (Prins & Loth, 1988) with an average of 529 mm (Peterson, 1978) during the short rains (October – January) and long rains (February – May) (Galanti *et al.*, 2006). Its undulating plateaus are mainly composed of dark red sandy clay loam soils, waterlogged areas, and flood plains of black cotton soils (Fig. 2), with elevations varying between 900 – 1200 masl (Kahurananga & Silkiluwasha, 1997; Galanti *et al.*, 2006).

Figure 1: Livestock grazing on Randilen WMA (left), whilst on the right is the area dominated by open grassland following the onset of short rain in 2019, in the Tarangire Manyara Ecosystem

Figure 2: Areas composed of black cotton soil (left) and dark red sandy clay loam soil (right) in 2019, in the Tarangire Manyara Ecosystem

The study area is predominantly classified as *Acacia Commiphora* savanna, comprised of open grasslands, woodlands, riverine forests, shrublands, or bushlands and falls in the semi-arid zone, based on rangeland classification by Pratt *et al.* (1966).

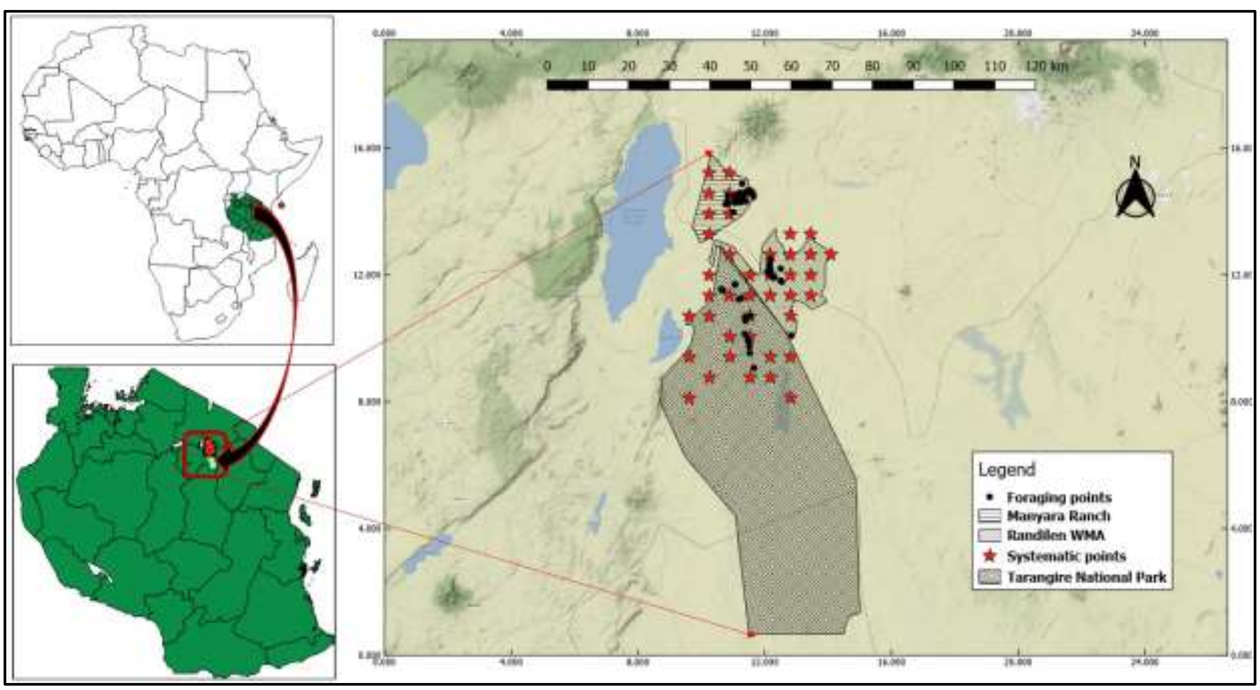

Figure 3: Map showing the systematic vegetation point transects (stars), at which landscape vegetation analyses were conducted, and the foraging points (black points) of giraffe groups that were opportunistically encountered while driving along the animal routes in the Tarangire Manyara Ecosystem in 2019

The TME represents one of the key remaining natural dry-season refugia for migratory ungulates in the country as well as a giraffe meta-population (Stoner *et al.*, 2007; Bolger *et al.*, 2008; Lee & Bolger, 2017). During the wet season, as food resources become abundant, wild herbivores are widely distributed across this human-influenced landscape (Galanti *et al.*, 2006) that is partly degraded, particularly in areas with less protection (Newmark *et al.*, 1994; Msoffe *et al.*, 2011).

3.2 Methods for Data Collection

3.2.1 Foraging Observations

Foraging observations were collected during 15 days per month in March and April 2019 (wet season observations), and August and September 2019 (dry season observations). Each day, giraffes were searched while driving in a car along the road network of the study area during daylight hours at a speed of 5–20 km/h. At an opportunistic encounter of a giraffe herd, 2-h observation records were made (Fig. 5). Foraging observations were obtained during each 2-h observation period, using instantaneous scan sampling (Martin & Bateson, 1993). The 5-min scans at 10-min intervals were conducted, using binoculars (10 × 50). Foraging events were recorded from the left to the right-hand side of the group in a first seen–first recorded style within 5 min (Martin & Bateson, 1993). In every scan, each plant species, and plant parts eaten by each foraging giraffe were identified and recorded within the group to assess general diet composition. Giraffes were followed as closely as possible without disturbing them, at a distance of 60–200 m. Herds were considered the sampling unit, so individual foraging data made during an observation period were summarized into proportional use by the entire herd (Fig. 3). The problem of group fusion was avoided by maintaining the original number of individuals that scans had started with. In the case of group fission, the researcher tried as much as possible to continue observing the same individuals and treating scattered individuals as a group. Observations were ended when some members of the group were no longer within our vicinity.

3.2.2 Vegetation Sampling

Forage plant availability was assessed at both local (within foraging patches) and landscape (entire study area) scales. Woody plants were identified directly in the field by a botanist while unidentified woody plant specimens were pressed in a plant press, assigned a collection number (symbol), and recorded in a field notebook for further identification. At both scales, the assessment was aimed at capturing proportions of available species considering both used and non-used forage resources (Bissonetie *et al.,* 1997).

i. Vegetation Sampling at the Local Spatial Scale

The local scale was intended to assess forage availability at a fine-scale of selection within areas where giraffes were observed foraging (Johnson, 1980; Manly *et al.,* 2002; Boyce, 2006). To quantify the availability of woody plant species at the local scale, vegetation strip transects of 10 m widths by 40 m lengths (Fig. 4) were sampled along giraffe routes at patches where giraffes had been observed foraging, immediately after the foraging herd had moved on (Fig. 4).

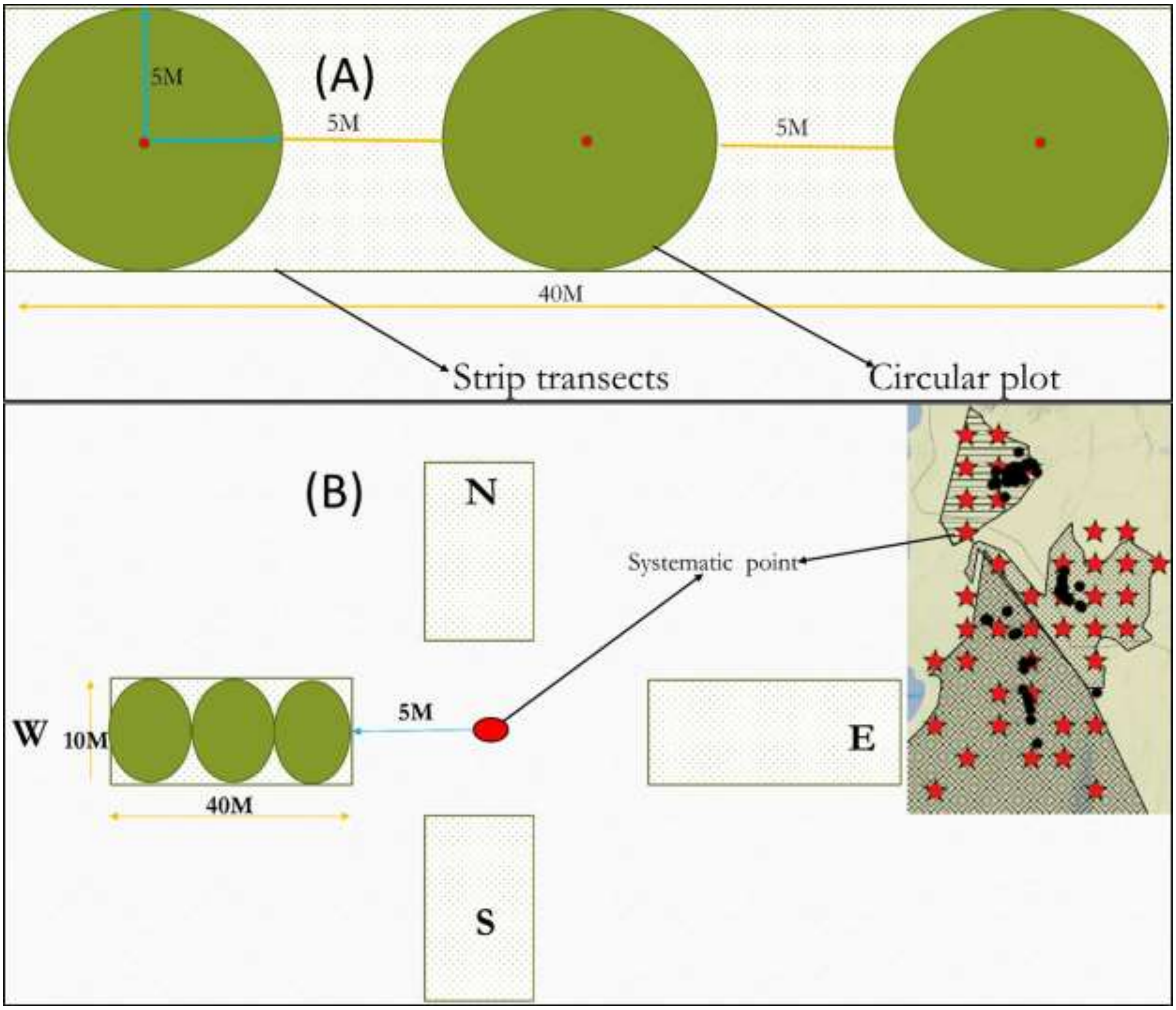

Figure 4: The layout of vegetation sampling at Local (A), and Landscape (B) spatial scales in 2019, in the Tarangire Manyara Ecosystem

In each foraging patch, three circular plots of 10 m in diameter were laid 5 m away from each other. Within each circular plot (Banda *et al.*, 2008; Chytry et *al.*, 2013), all woody species were identified, and determined the percent cover for each forage species.

ii. Vegetation Sampling at Landscape Spatial Scale

To quantify forage availability at the landscape scale, systematic vegetation sampling was conducted within the area where giraffes had been seen regularly for the last 6 years (Lee & Bond, 2016; Lee *et al.*, 2016; Lee & Bolger, 2017). Forty-four (44) points were were established systematically across the landscape using QGIS 2.18.12; all points were 5 km apart. At each point, four “strip transects” of 40 × 10 m were established to the North, East, South, and West (Lindgren & Sullivan, 2001) as illustrated in Fig. 4 and Fig. 5. Within each strip transect, woody vegetation was recorded the following the same three-circular-plot methodology as used for the local vegetation assessment. Data on available woody plants were collected in March and April 2019 (wet season observations) and in August and September 2019 (dry season observations).

Figure 5: Researcher (Matana) and a driver (Oscar) gathering foraging observations (left), Researcher (Matana) and field assistant (Erasto) collecting vegetation data (right) in 2019, in the Tarangire Manyara Ecosystem

3.3 Methods for Data Analysis

To understand which plants were selected by giraffes, all woody plant species consumed by giraffes were listed. Proportional use (P_o) of each woody plant species per herd was determined by taking the number of foraging records for each forage species divided by the total number of foraging records for that herd. This was followed by computing an overall average proportion use of woody plant species (P_o) across all herds. Local-scale proportional availability (local P_a) of all woody plant species for the foraging route taken by each herd was computed using each species’ average percent cover for the three circular plots. Landscape-scale available proportions (landscape P_a) for each woody plant species were obtained by taking the average percent cover of all woody plant species from the systematic vegetation sampling.

Chi-squared test was used to determining whether species were used in proportion to their availability using the equation

$$(\chi^2 = \frac{\Sigma(fo - fe)^2}{fe}) \quad (1)$$

Where f_o is an observed sample frequency on woody plant species i across the entire area, and f_e is an expected value of f_o obtained by multiplying the total number of observed forage frequency in all resource category with proportional availability (relative of each woody plant species i (Manly *et al.*, 2002). Here the standard normal distribution was compared under the assumption that each species was eaten at least once, and <20% of all forage categories contain <5 expected forage observations (Neu *et al.*, 1974; Dixon & Massey, 1969). As such, only 20 forage species with > 5 forage observations (Manly *et al.*, 2002) were used from 38 forage categories for the chi-squared test.

Manly's selection ratio ($\hat{W}$; Eq. 2) was used to determine forage selection indices for each woody plant species using the equation

$$(\hat{W}i) = P_o/P_a \quad (2)$$

Where P_o is the proportion of foraging observations on woody plant species i across the entire area, and P_a is the proportional availability (relative percent cover) of woody plant species i (Manly *et al.*, 2002). Local- (within-herd route) and landscape-scale selection ratios ($\hat{W}i$) were determined. Bonferroni confidence intervals (Eq. 3; Manly *et al.*, 2002) were used to determine whether there was significant selection or avoidance of each woody species (Neu *et al.*, 1974). Selection or avoidance was statistically significant if the confidence interval (*CI*) of $\hat{W}i$ for a particular species did not include 1, whereas no selection occurs if the *CI* of $\hat{W}i$ includes 1. Bonferroni confidence intervals were constructed using the formula

$$CI = \hat{W}i \pm z\alpha/2k * Se(\hat{W}) \quad (3)$$

where $\alpha/2k$ accounts for multiple comparisons at 95% confidence limits (α = 0.05) while constructing the critical z-value table, k is the total number of used woody plant species, $Se(\hat{W})$ is the standard error of resource selection, and $\hat{W}i$ is the selection coefficient for woody plant species i.

To further understand the seasonal difference in species-specific forage selection, standard errors for the differences in forage selection coefficients (Eq. 4) for each forage species were calculated using the formula

$$\Delta S.E. = \frac{(\hat{W}i)d-(\hat{W}i)w}{\sqrt{(Se\hat{W}d)^2+(Se\hat{W}w)^2}}, \qquad (4)$$

Where ΔS.E. is the standard error for the differences in forage selection coefficients, $(\hat{W}i)d$ and $(\hat{W}i)w$ are the selection ratios for the dry and wet seasons for woody plant species *i*, $Se\hat{W}d$ and $Se\hat{W}w$ are standard errors of forage selection coefficients for the dry and wet seasons for woody plant species *i*, respectively. *p-values* were computed based on the standard error of the differences in seasonal and spatial scale forage selection for each woody plant species (Appendix 2). The Chi-square goodness of fit test was used to compare the frequency distribution of the twenty most selected dietary options across the seasons (Berry & Bercovitch, 2016). To see if animal diet diversity differed between the wet and dry seasons, the same twenty selected species in the wet season were used and matched those species across the season, then calculated the Shannon-Wiener diversity index (Berry & Bercovitch, 2016) using the formula

$$H' = \sum_{i=1}^{n}[p_o \ x \ ln(p_o)] \qquad (5)$$

Where p_o is the proportion of observed feeding records on each woody plant species, and H' is the index of dietary diversity.

To understand the giraffe herd distribution and habitat selection under different protection statuses, a land cover classification was done using the Arc Map 10.3 software with Landsat images (for 2018) from the United States Geological Survey (USGS). A total of 182 training areas were sampled across the landscape, then digitized using high-resolution Google Earth imagery. Three main land cover classes visited by giraffes for foraging in the TME were identified and classified; woodland, shrubland, and grassland. Grassland referred to the vegetation class dominated by grasses and forbs interspersed with < 2% scattered trees and shrubs, whereas shrubland represented a vegetation type chiefly made up of > 20% shrubs, many of which have heights below 2m and <10% scattered trees (Pratt, 1966). Woodland vegetation type was a mix of trees and shrubs with > 20% tree canopy interlaced with <10% shrub cover.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Diet Composition and Forage Selection

Instantaneous scan sampling produced 3 728 individual foraging observations during 1 250 scans of 105 giraffe herds. Giraffes were encountered in herds with an overall size of 7 ± 5 (max = 20, min = 2) individuals, composed of 86% adults, 11% sub-adults, and 3% juveniles in the wet season. During the dry season, average giraffe group sizes were slightly lower with 5 ± 3 (max = 13, min = 1) individuals, composed of 83% adults, 13% sub-adults, and, 4% juveniles.

In vegetation sampling plots across the landscape (n = 44) and local-scale (n = 105) within TME, 118 woody plant species were identified. Giraffes consumed 38 out of these 118 species, with 33 and 29 of the foraged species consumed in the dry and wet seasons, respectively (Table 1). The choices of plant parts fed upon by giraffes in the wet season were not significantly different from that of the dry season (t = 0.095, p = 0.927). Selected plant parts were 74% young leaves, 10% plant shoots, 8% leaf buds, 7% mature leaves, and <1% plant fruits during the wet season. During the dry season, 66% young leaves, 21% mature leaves, 7% plant shoots, 4% fruits, 2% leaf buds, and <1% flowers were eaten (Fig. 6).

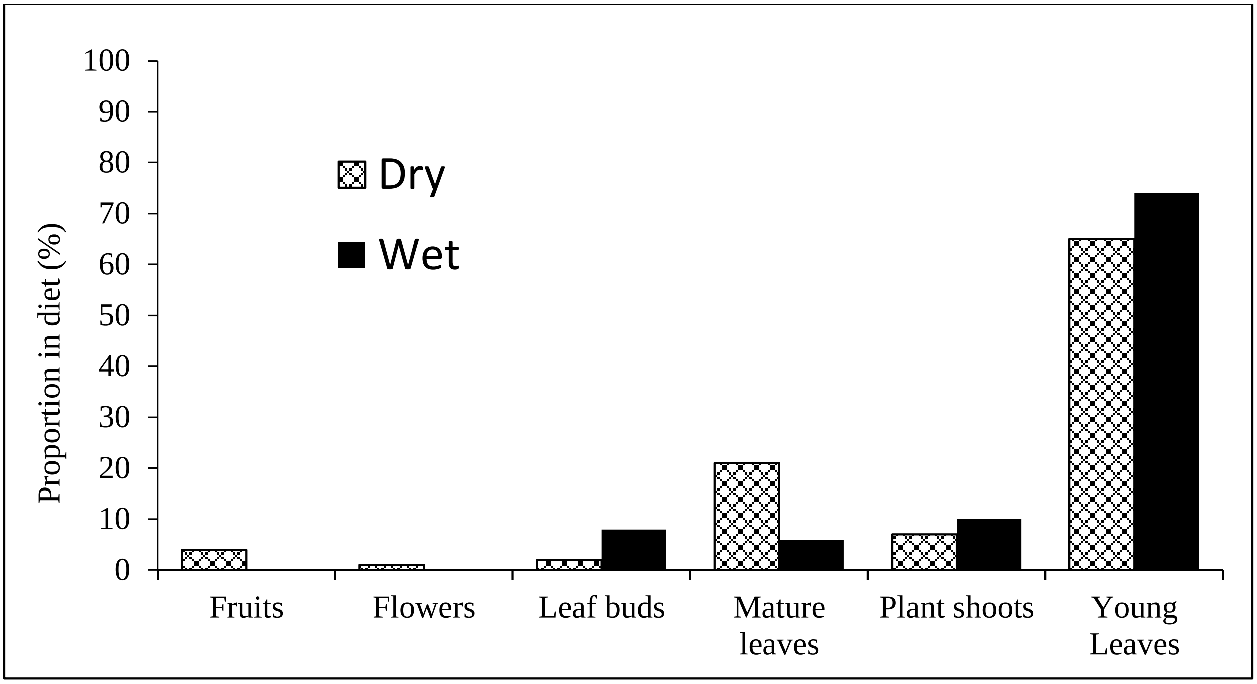

Figure 6: Percentage of different plant parts of the diet of giraffes, in 2018 in the Tarangire Manyara Ecosystem based on direct observations from 1 250 scans of 105 giraffe herds

The most-consumed plant species in both the wet and dry seasons were *Vachellia tortilis* (25%), *Dichrostachys cinerea* (23%), *Vachellia mellifera* (17%), *Vachellia drepanolobium* (9%), *Balanites aegyptiaca* (7%), *Vachellia kirkii* (4%), *Dalbergia melanoxylon* (4%), *Maerua triphylla* (2%), and *Ziziphus mucrunata* (1%) (Table 1). As predicted, giraffes were highly selective in their foraging. The study found a year-round giraffe foraging preference for *D. cinerea*, *V. drepanolobium*, *V. mellifera*, and *V. tortilis* (Fig. 7). Further, giraffes avoided some woody species such as *Adansonia digitata, Euphorbia candelabrum, Commiphora africana, Commiphora schimperii, and Kigelia africana*. Giraffe use of woody plant species for foraging differed significantly from the plant species' proportional availability at local scale ($\chi^2 = 403$, $df = 19$, $p < 0.001$) and at the landscape scale ($\chi^2 = 955$, $df = 19$, $p < 0.001$).

Table 1: Woody plant species consumed by Masai giraffes (*Giraffa camelopardalis tippelskirchi*) in the Tarangire Manyara Ecosystem of Tanzania in both dry and wet season, 2019, and their proportions in the diet (*Po*) over the entire year (2019) and split up into the dry and wet season

Woody species	Contribution to diet (*Po*)			Availability (*Pa* local)			Availability (*Pa* landscape)
	year	dry	wet	year	dry	wet	yearly
Vachellia tortilis	0.253	0.161	0.344	0.169	0.166	0.173	0.166
Dichrostachys cinerea	0.227	0.295	0.159	0.143	0.158	0.128	0.072
Vachellia mellifera	0.167	0.219	0.114	0.124	0.142	0.107	0.053
Vachellia drepanolobium	0.088	0.066	0.109	0.064	0.058	0.069	0.022
Balanites aegyptiaca	0.072	0.052	0.092	0.069	0.066	0.073	0.045
Vachellia kirkii	0.045	0.011	0.078	0.021	0.007	0.035	0.032
Dalbergia melanoxylon	0.036	0.035	0.038	0.054	0.073	0.036	0.061
Maerua triphylla	0.022	0.032	0.012	0.030	0.020	0.040	0.027
Strychnos potatorum	0.020	0.019	0.021	0.013	0.006	0.020	0.012
Combretum zeyheri	0.015	0.030	0.000	0.006	0.011	0.001	0.032
Commiphora schimperii	0.007	0.004	0.010	0.027	0.025	0.029	0.024
Ziziphus mucronata	0.005	0.011	0.000	0.004	0.008	0.000	0.006
Lanchocarpus eriocalyx	0.005	0.010	0.000	0.010	0.018	0.003	0.015
Harrisonia abyssinica	0.005	0.010	0.000	0.007	0.009	0.006	0.005
Capparis fascularis	0.005	0.007	0.002	0.028	0.033	0.023	0.008
Vachellia nilotica	0.004	0.008	0.000	0.023	0.038	0.007	0.005
Ficus natarensis	0.004	0.007	0.000	0.000	0.000	0.000	0.000
Albizia anthelmintica	0.004	0.005	0.002	0.017	0.003	0.030	0.048
Carrisa spinorum	0.002	0.005	0.000	0.003	0.006	0.000	0.003
Combretum molle	0.002	0.004	0.000	0.006	0.009	0.003	0.018
Cordia monoica	0.002	0.000	0.004	0.007	0.000	0.014	0.006
Salvadora persica	0.002	0.003	0.001	0.011	0.004	0.018	0.001
Vachellia senegal	0.001	0.000	0.003	0.015	0.013	0.017	0.007
Gardenia tenufolia	0.001	0.000	0.002	0.001	0.002	0.000	0.000
Ozoroa insignis	0.001	0.000	0.002	0.001	0.001	0.002	0.005
Kigelia africana	0.001	0.000	0.001	0.011	0.013	0.009	0.014
Ximenia caffra	0.001	0.001	0.001	0.003	0.005	0.001	0.003
Boswelia negleta	0.001	0.001	0.000	0.000	0.000	0.000	0.002
Lannea edulis	0.001	0.000	0.001	0.004	0.006	0.003	0.009
Scolopia zeyheri	0.001	0.001	0.000	0.001	0.001	0.000	0.000
Vachellia seyal	0.001	0.000	0.001	0.004	0.008	0.000	0.000
Euphorbia candelabrum	0.000	0.000	0.001	0.002	0.000	0.005	0.013
Fluggea virosa	0.000	0.000	0.001	0.007	0.010	0.003	0.003
Vachellia xanthophloea	0.000	0.000	0.001	0.001	0.003	0.000	0.000
Commiphora africana	0.000	0.000	0.001	0.013	0.017	0.010	0.018

Woody species	Contribution to diet (*Po*)			Availability (*Pa* local)			Availability (*Pa* landscape)
	year	dry	wet	year	dry	wet	yearly
Capparis sepiaria	0.000	0.001	0.000	0.000	0.000	0.000	0.001
Boscia mosambisensis	0.000	0.000	0.000	0.003	0.001	0.005	0.001
Adansonia digitata	0.000	0.000	0.000	0.051	0.021	0.081	0.033

Note: *Pa* indicates the proportional availability at local (*Pa* local) and landscape (*Pa* landscape) spatial scales

4.1.2 Seasonal Forage Selection

Selection ratios and the confidence intervals of the differences in selection for each forage species revealed some seasonally significant differences in selection indices for some woody species (Table 2, Fig. 7, and Appendix 2). Giraffe dietary diversity was ($H' = 1.99$) during the wet season but reduced to ($H' = 1.78$) during the dry season. Giraffes fed on 29 plant species (N = 1 555 records) during the wet season and 33 plant species (N = 2 173 records) during the dry season. The twenty most frequently eaten plant species contributed to nearly 100% during the wet season of the animal diet but accounted for only 91% of the diet during the dry season. Composition of dietary item (plant species) did not vary between wet and dry season at local spatial scale ($\chi^2 = 8.3333$, $df = 10$, $p = 0.5963$) but differed significantly between the dry and wet seasons at landscape scale ($\chi^2 = 26.917$, $df = 9$, $p = 0.0014$).

Table 2: Giraffe local- and landscape-scale forage selection ratios (Ŵ), and *p*-values indicating significant differences across seasons for 38 woody plant species in the Tarangire Manyara Ecosystem, for both dry and wet season, of the year 2019

Woody species	Local Selection			Landscape Selection		
	Dry (Ŵ)	Wet (Ŵ)	∆seasonal *p*	Dry (Ŵ)	Wet (Ŵ)	∆seasonal *p*
Adansonia digitata	0.01	0.00	0.985	0.01	0.00	0.446
Albizia anthelmintica	2.08	0.06	0.040*	0.13	0.04	0.060
Balanites aegyptiaca	0.80	1.26	0.574	1.56	2.73	<0.001**
Boscia mosambisensis	0.36	0.00	0.693	0.24	0.00	0.366
Boswelia negleta	-	-	-	-	-	-
Capparis fascularis	0.21	0.10	0.879	0.80	0.25	0.033*
Capparis sepiaria	-	-	-	-	-	-
Carrisa spinorum	0.81	-	-	1.12	0.00	0.003*
Combretum molle	0.51	0.00	0.542	0.19	0.00	0.004*
Combretum zeyheri	2.70	0.00	0.005*	0.74	0.00	<0.001**
Commiphora africana	0.00	0.06	0.936	0.00	0.03	0.345
Commiphora schimperii	0.17	0.35	0.818	0.13	0.32	0.049*
Cordia monoica	-	0.27	-	0.00	0.62	0.020*
Dalbergia melanoxylon	0.48	1.06	0.486	0.44	0.49	0.572
Dichrostachys cinerea	1.87	1.24	<0.0001*	3.54	1.91	<0.001**
Euphorbia candelabrum	-	0.19	-	0.00	0.08	0.252
Ficus natarensis	-	-	-	16.19	0.00	<0.001**
Flaggea virosa	0.00	0.30	0.737	0.00	0.25	0.261
Gardenia tenufolia	0.00	-	-	0.00	20.78	0.060
Harrisonia abyssinica	1.19	0.00	0.182	1.77	0.00	<0.001**
Kigelia africana	0.02	0.14	0.886	0.02	0.11	0.308
Lanchocarpus eriocalyx	0.58	0.00	0.478	0.52	0.00	<0.001**
Lannea edulis	0.00	0.42	0.640	0.00	0.11	0.167
Maerua triphylla	1.57	0.30	0.144	2.36	0.89	<0.001**
Ozoroa insignis	0.00	1.28	0.195	0.00	0.31	0.088
Salvadora persica	0.63	0.05	0.511	2.28	0.85	0.240

Woody species	Local Selection			Landscape Selection		
	Dry (Ŵ)	**Wet (Ŵ)**	**Δseasonal *p***	**Dry (Ŵ)**	**Wet (Ŵ)**	**Δseasonal *p***
Scolopia zeyheri	1.11	-	-	-	-	-
Strychnos potatorum	3.11	1.05	0.034*	1.83	1.97	0.756
Vachellia drepanolobium	1.13	1.59	0.581	2.55	4.24	<0.001**
Vachellia kirkii	1.76	2.21	0.623	0.34	2.30	<0.001**
Vachellia mellifera	1.55	1.07	0.546	3.42	1.77	<0.001**
Vachellia nilotica	0.22	0.05	0.828	1.34	0.06	<0.001**
Vachellia senegal	0.00	0.16	0.837	0.00	0.31	0.047**
Vachellia seyal	0.00	-	-	-	-	-
Vachellia tortilis	0.97	1.99	0.199	1.33	2.84	<0.001**
Vachellia xanthophloea	0.00	-	-	-	-	-
Ximenia caffra	0.24	0.55	0.742	0.33	0.18	0.615
Ziziphus mucronata	1.26	-	-	1.34	0.00	<0.001**

Note: Selection ratios are based on Manly et al. (2002). If Ŵ > 1 then species preferred, If Ŵ <1 then species avoided, If $p < 0.05$, then the species was significantly preferred/avoided (marked by"*"). Zeros or missing values were obtained if either foraged or available proportions were zero

4.1.3 Forage Selection and Protection Status

The selection indices indicated a significant difference in forage preference and avoidance for some woody plant species across the three protected areas (Table 3). Giraffes preferred a relatively large number of woody plant species in less protected areas than in a fully protected area, i.e., five species were preferred in Manyara Ranch, three in Randilen WMA, and one in the fully protected area (Tarangire National Park). Besides, 42 herds were encountered in Manyara Ranch, 32 in Randilen WMA, and 31 in the fully protected area (Tarangire National Park) (Fig. 3 and Fig.10).

Table 3: Giraffe (*Giraffa camelopardalis tippelskirchi*) forage selection ratios (Ŵ), and their Bonferroni confidence intervals (CI Ŵ) for 38 woody plant species in three study sites (Tarangire National Park (TNP), Randilen WMA (RD), and Manyara Ranch (M.R.) in Tanzania, 2019

Woody species	Available proportions			Forage Selection			Confidence Intervals					
	TNP	RD	M.R	TNP	RD	M.R	TNP		RD		M.R	
							Lower	High	Lower	High	Lower	High
Adansonia digitata	0.01	0.03	0.01	0.01	0.00	-	**-0.02**	**0.03**	**0.00**	**0.00**	-	-
Albizia anthelmintica	0.23	0.11	0.17	0.69	0.08	0.24	**-0.08**	**1.47**	**-0.07**	**0.24**	**-0.26**	**0.74**
Balanites aegyptiaca	0.07	0.13	0.17	0.26	1.00	1.39	**0.05**	**0.47**	**0.65**	**1.34**	**1.07***	**1.72***
Boscia mosambisensis	0.00	0.00	0.00	-	0.08	-	-	-	**-0.20**	**0.37**	-	-
Boswelia negleta	0.00	0.05	0.01	-	-	-	-	-	-	-	-	-
Capparis fascularis	0.01	0.01	0.15	0.25	0.00	0.18	**-0.33**	**0.83**	**0.00**	**0.00**	**0.03**	**0.32**
Capparis sepiaria	0.01	0.06	0.00	-	-	-	-	-	-	-	-	-
Carrisa spinorum	0.00	0.00	0.03	-	1.18	0.00	-	-	**0.06**	**2.3**	**0.00**	**0.00**
Combretum molle	0.00	0.01	0.01	0.00	0.49	-	**0.00**	**0.00**	**0.01**	**0.98**	-	-
Combretum zheyeri	0.09	0.07	0.00	-	2.58	-	-	-	**1.63***	**3.53***	-	-
Commiphora africana	0.00	0.01	0.00	0.00	0.00	0.31	**0.00**	**0.00**	**0.00**	**0.00**	**-0.71**	**1.32**
Commiphora schimperii	0.00	0.00	0.00	0.01	0.34	0.53	**-0.05**	**0.07**	**0.04**	**0.64**	**0.06**	**1.01**
Cordia monoica	0.06	0.06	0.08	0.65	0.00	0.04	**-0.25**	**1.55**	**0.00**	**0.00**	**-0.15**	**0.23**
Dalbergia melanoxylon	0.01	0.01	0.06	1.25	0.17	0.34	**0.85**	**1.66**	**-0.04**	**0.38**	**0.15**	**0.53**
Dichrostachys cinerea	0.12	0.16	0.15	0.90	2.43	1.69	**0.71**	**1.10**	**2.17***	**2.7***	**1.36***	**2.02***
Euphorbia candelabula	0.00	0.02	0.00	-	0.23	0.00	-	-	**-0.35**	**0.81**	**0.00**	**0.00**
Ficus natarensis	0.04	0.00	0.00	-	-	-	-	-	-	-	-	-
Flaggea virosa	0.04	0.03	0.02	1.05	0.00	0.00	**-1.91**	**4.01**	**0.00**	**0.00**	**0.00**	**0.00**
Gardenia tenufolia	0.00	0.00	0.00	-	0.00	-	-	-	**0.00**	**0.00**	-	-
Harrisonia abyssinica	0.00	0.01	0.00	-	0.90	0.00	-	-	**0.32**	**1.48**	**0.00**	**0.00**
Kigelia africana	0.00	0.02	0.00	0.13	0.00	-	**-0.14**	**0.4**	**0.00**	**0.00**	-	-
Lanchocarpus eriocalyx	0.12	0.16	0.15	0.00	0.78	0.30	**0.00**	**0.00**	**0.27**	**1.29**	**-0.59**	**1.2**
Lannea edulis	0.00	0.01	0.00	-	0.17	0.00	-	-	**-0.18**	**0.52**	**0.00**	**0.00**
Maerua triphylla	0.00	0.00	0.00	0.96	0.00	0.00	**0.63**	**1.29**	**0.00**	**0.00**	**0.00**	**0.00**
Ozoroa insignis	0.00	0.01	0.01	0.00	1.00	-	**0.00**	**0.00**	**-0.67**	**2.68**	-	-
Salvadora persica	0.00	0.00	0.00	0.00	0.00	0.21	**0.00**	**0.00**	**0.00**	**0.00**	**-0.05**	**0.46**
Scolopia zheyeri	0.00	0.02	0.00	-	1.11	-	-	-	**-1.13**	**3.36**	-	-
Strychnos potatorum	0.02	0.02	0.00	1.52	2.30	-	**0.87**	**2.16**	**0.59**	**4.00**	-	-
Vachellia drepanolobium	0.01	0.01	0.14	0.00	0.00	1.45	**0.00**	**0.00**	**0.00**	**0.00**	**1.22***	**1.69***
Vachellia kirkii	0.00	0.01	0.00	1.13	2.56	0.19	**-0.70**	**2.96**	**1.97***	**3.15***	**-0.24**	**0.61**
Vachellia mellifera	0.07	0.03	0.07	1.12	0.77	1.80	**0.73**	**1.51**	**0.56**	**0.97**	**1.57***	**2.03***
Vachellia nilotica	0.03	0.01	0.00	0.00	0.25	0.00	**0.00**	**0.00**	**0.07**	**0.42**	**0.00**	**0.00**
`Vachellia senegal	0.08	0.01	0.01	-	0.35	0.06	-	-	**-0.59**	**1.29**	**-0.05**	**0.18**
Vachellia seyal	0.00	0.00	0.00	-	0.00	0.15	-	-	**0.00**	**0.00**	**-0.26**	**0.57**
Vachellia tortilis	0.00	0.00	0.00	2.04	1.21	0.95	**1.82***	**2.26***	**0.93**	**1.49**	**0.77**	**1.13**

Woody species	Available proportions			Forage Selection			Confidence Intervals					
	TNP	RD	M.R	TNP	RD	M.R	TNP		RD		M.R	
							Lower	High	Lower	High	Lower	High
Vachellia xanthophloea	0.00	0.00	0.02	-	0.00	-	-	-	0.00	0.00	-	-
Ximenia caffra	0.00	0.01	0.00	-	0.00	1.82	-	-	0.00	0.00	**-1.52**	**5.16**
Ziziphus mucrunata	0.01	0.00	0.00	0.00	0.37	3.86	**0.00**	**0.00**	**-0.46**	**1.19**	**1.09***	**6.62***

Note: The selection coefficient is significant if the confidence interval for Ŵ does not contain the value 1. If CI Ŵ > 1, then significantly preferred (Highlighted green*), if CI Ŵ < 1, then significantly avoided (Red text), if CI Ŵ includes 1, then used in proportion to availability (Bold text). Zeros or missing values were obtained if either foraged or available proportions were zero

4.1.4 Spatial Scales and Forage Resource Use

Giraffes foraged non-randomly at both at local scale (χ^2 = 403, *df* = 19, *p* < 0.001) and at the landscape scale (χ^2 = 955, *df* = 19, *p* < 0.001). Giraffes preferred *V. tortilis, V. mellifera*, and *V. drepanolobium* consistently throughout the year (Fig. 7; Appendix 2, and Appendix 3. In contrast to what was predicted, giraffes exhibited a high and year-round preference for the native shrub *D. cinerea* at both local and landscape scales (Fig. 7; Appendix 2, and Appendix 3). Giraffes also avoided some woody species such as *Kigelia africana*, *Commiphora schimperii*, *Commiphora africana*, *Adansonia digitata, and Euphorbia candelabrum* (Fig. 7; Appendix 2; Appendix 3).

i. Forage Selection at the Local Spatial Scale

Giraffes used forage resources proportionally more than based on their availability at the local spatial scale (χ^2 = 374, *df* = 15, *p* < 0.001), in both dry (χ^2 =323, *df* = 19, *p* < 0.05) and wet seasons (χ^2 =237, *df* = 16, *p* = 0.001). Giraffes demonstrated a strong preference for the species *Dichrostachys cinerea, V. tortilis, V. drepanolobium*, and *V. kirkii* at local scale during the wet season (Fig. 7). During the dry season *D. cinerea, V. mellifera, Strychnos potatorum* and *Combretum zeyheri* were selected more than their proportional availability. Giraffes used *Balanites aegyptiaca, Carrisa spinorum, Scolopia zeyheri* and *Ziziphus mucronata* proportional to their relative abundance throughout the year at local scale and avoided *Adansonia digitata*, *Capparis fascularis*, *Cordia monoica*, *Commiphora schimperii*, *Euphorbia candelabrum*, *Kigelia africana*, *Lanchocarpus eriocalyx*, *V. nilotica*, and *V. senegal* in both the wet and dry seasons (Fig. 7; Appendix 2).

ii. Forage Selection at Landscape Spatial Scale

Forage resources were used disproportionately to their availability at the landscape scale (χ^2 =955, *df* = 19, *p*<0.0001). Selection was significant for both dry (χ^2 =898, *df* = 19, *p*<0.0001) and wet (χ^2 =604, *df* = 19, *p*<0.0001) seasons. At the landscape scale, *B. aegyptiaca, D. cinerea, V. drepanolobium, V. mellifera,* and *V. tortilis* were the most preferred forage species throughout the year. During the wet season, *B. aegyptiaca, D. cinerea, V. drepanolobium, V. mellifera, V. tortilis,* and *V. kirkii* were preferred while in the dry season giraffe preferred foraging on *B. aegyptiaca*, *D. cinerea*, *Ficus natarensis, Maerua triphylla, V. drepanolobium, V. mellifera,* and *V. tortilis* (Fig. 7).

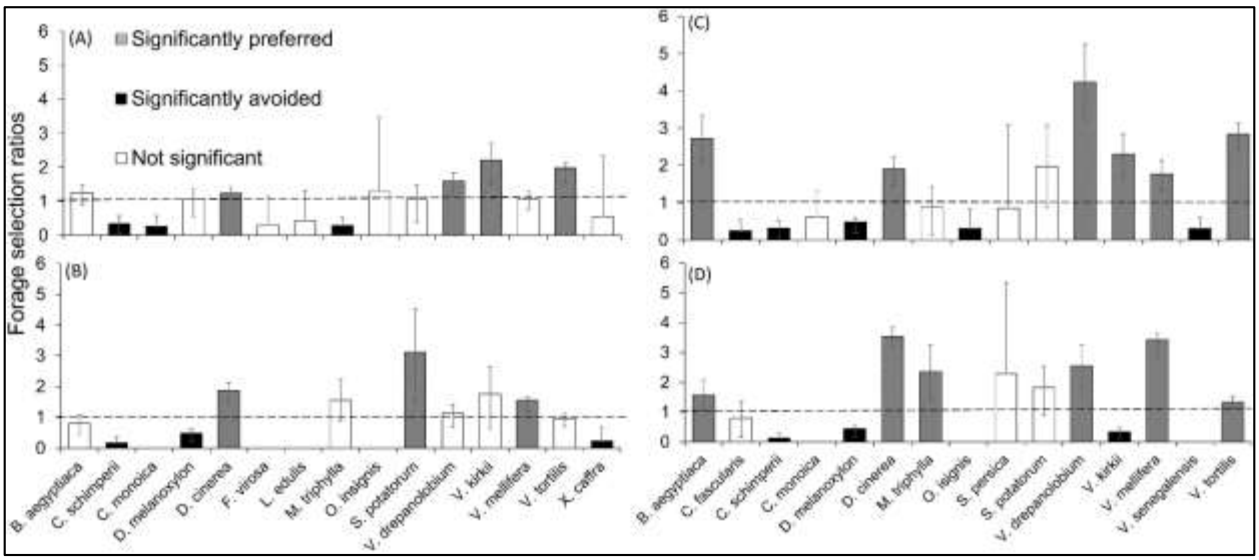

Figure 7: Local- (A and B) and landscape-scale (C and D) forage selection ratios and direction of forage selection indicated by confidence intervals (Ŵ ± CIs) for the 15 most frequently selected forage species by Masai giraffes during both the wet (A and C) and dry season (B and D) in the TME., in 2019

4.2 Discussion

4.2.1 Diet Composition and Forage Selection

The diet of Masai giraffes in the Tarangire Ecosystem consisted of a variety of woody plant species and confirmed previous studies in other regions (Pellew, 1984b; Parker & Bernard, 2005; Dagg, 2014; Berry & Bercovitch, 2016) that giraffes will forage on many plant species but concentrate on a narrow range of forage options, most notably *Vachellia* species (Fig. 8) For example, in the Serengeti National Park, five forage species accounted for about 70% of the giraffe's diet (Pellew, 1984b). Parker and Bernard (2005) assessed the giraffe diet in the Eastern Cape Province of South Africa, where 46 forage species were consumed, but *Vachellia karroo* and *Rhus longispina* comprised 60% of the total diet.

Figure 8: Giraffes foraging on *D. cinerea* (left) and *V. tortilis* (right) during the wet season (April 2019) in the Tarangire Manyara Ecosystem

In a recent study by Mahenya *et al.* (2016a) in Arusha National Park in Tanzania, the giraffes' diet was 90% composed of *V. xanthophloea*. Similarly, in this study in the Tarangire Ecosystem, *D. cinerea* and *Vachellia* species contributed about 65% of the overall giraffe diet. Selection for *D. cinerea* and *Vachellia* species was likely due to the high nutritional value and digestibility of these woody plant species (Sauer, 1983; Pellew, 1984a). Giraffes also demonstrated strong avoidance of some woody species such as *K. africana* and *A. digitata*, likely because of their poor digestibility (Woodward & Coppock, 1995; Proll *et al.*, 2018).

The giraffe forage preferences towards a handful of total dietary options are similar to that of other mammalian herbivores. Foraging specificity was also observed for Zebra (*Equus zebra*), which foraged on 15 identified grass species in South Africa, where *Themeda triandel and Tristachya leucothrix* accounted for 67% of the total animal diet (Weel *et al.*, 2015). Likewise the dietary composition of chimpanzees (*Pan troglodytes*) in Kibale National Park, Uganda reported having been made of 70% fruits (Watts *et al.*, 2011), while African elephants (*Loxodonta africana*) in Amboseli National Park, Kenya, restricted their foraging to 5 species out of 91 identified forage species (Lindsay, 2011).

4.2.2 Seasonal Forage Selection

Differences in seasonal forage selection by Masai giraffes for particular plant species were detected at both the local and landscape scale, probably because of a decrease in forage plant availability during the dry season compared to the wet season (Beyer & Haufler, 1994; Whittingham *et al.*, 2005; Boyce, 2006). Masai giraffes appear to demonstrate seasonal forage use toward a few species to guarantee sufficient amount and nutrient content of food (Sauer *et al.*, 1977; Sauer, 1983; Pellew, 1984b; Parker *et al.*, 2003). Most deciduous woody plants such as *C. zeyheri, D. cinerea, V. kirkii, V. mellifera, and V. tortilis* contributed strongly to giraffe diet during the wet season, but some became less important in the dry season, in agreement with similar studies (Sauer, 1983; Pellew, 1984b). For example, the preferred V. kirkii, a shrub species that grows best in waterlogged areas during the wet season, was strongly avoided foraging during the dry season. This was also highlighted by Sauer *et al.* (1977), Sauer (1983), Pellew (1984a), and Hall-Martin and Basson (1974), who all found that giraffes preferably fed on deciduous woody plants during the wet season. These authors observed changes in giraffe foraging patterns during the course of the dry season as deciduous plants start losing their leaves, resulting in a cascading effect in the availability of deciduous plant material. During this period of reduced forage abundances, giraffes tend to search for more forage options, including those species which are ignored during the wet season. However, *Balanites aegyptiaca* (Fig. 11) and *Strychnos potatorum* are evergreen trees throughout the year (Gebrekirstos *et al.*, 2006; Sharma & Banu, 2017). As such, these plants guarantee a constant supply of forage resources in both wet and dry seasons, and giraffes never avoided foraging upon them.

In the present study, giraffe foraging preferences switched to semi-deciduous plants, most notably *Combretum species* (Fig. 9), which retain their leaves and protein content as the dry season progresses (Sauer, 1983). Reduced forage availability in shrub-dominated areas during the dry season resulted in an extension of the giraffe foraging range into less frequently visited habitats, such as *Commiphora–Combretum*-dominated woodland. These results are in line with those obtained by Sauer (1983) that the selection of *Vachellia species* often declines in the dry season due to a decrease of protein and water content, while *Combretum species* loses its proteins more slowly, making it a suitable forage source for longer into the dry season. The cause for seasonal species-specific preference in both spatial scales could be the high plant vigor coupled with an increase of nutritional values during the wet season (Hall-Martin & Basson, 1974; Sauer, 1983; Pellew, 1984a). In contrast, the avoidance of forage species with the course of the dry season would have resulted from a significant depletion with regard to availability and nutritional value of these forage options (Pellew, 1984b; Berry & Bercovitch, 2016).

Figure 9: Giraffe feeding on semi-deciduous plant, *C. zeyheri* (right) whilst stands of *V. kirkii* were dried up (left) during the dry season in TME during the month September 2019

Results contradicted the prediction that the giraffe diet would be composed of relatively fewer plant species (33 species) in the dry season than in the wet season (29 species). These results also opposed that of a previous study by Berry and Bercovitch (2016) in Zambia, where giraffes foraged on relatively fewer (72) species in the dry season than (78) in the wet season. The hypothesized basis of this difference could be a result of the sudden increase of giraffe range into another habitat, such as *Commiphora–Combretum* dominated woodland with the course of the dry season (Fig. 10), thus bringing in additional forage options compared to the wet season.

One limitation of this study is that it lasted for only one year and collected foraging observations for only four weeks total, which is less compared to 40 years of foraging observations made by Berry and Bercovitch (2016) in the Luangwa valley. For that reason, a longer-term resource assessment would probably end up with a longer list of forage species reflecting the entire sampling population. However, the findings of this study are critical for establishing baseline information, and as substantial grassroots for further comprehensive studies on resource use versus availability.

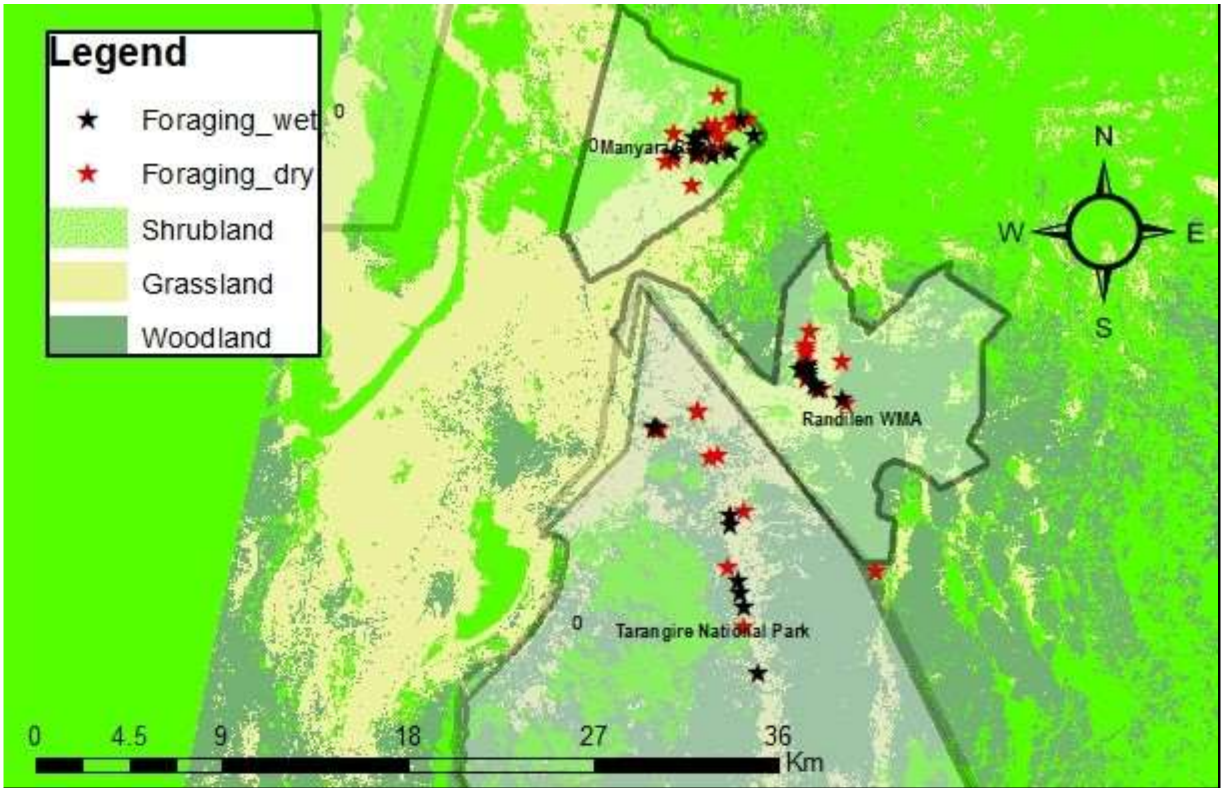

Figure 10: A classified Landsat image showing distribution of giraffe herds in three different habitats (Woodlands, Shrublands, and Grasslands), and protected areas (Manyara Ranch, Randilen WMA, and the Tarangire National Park) for both dry (red stars) and wet (black stars) season in the Tarangire Manyara Ecosystem, 2019

Figure 11: Giraffe feeding on an evergreen plant, *Balanites aegyptiaca*, in the dry season (left) whereas in the right picture, the giraffe forages on growing shoots of *Vachellia tortilis* following the onset of the short rains in 2019, in the Tarangire Manyara Ecosystem

Figure 12: Following the onset of the wet season, *D. cinerea* stands growing (left), whilst in the right is severely browsed stands of *D. cinerea* in the Tarangire Manyara Ecosystem, in 2019

4.2.3 Forage Selection and Protection Status

The study found that giraffes preferred more woody plant species in less protected areas (Manyara Ranch and Randilen WMA) than in a fully protected area (Tarangire National Park). A large number of preferred woody species perceived in less protected areas could be attributed to the rapid expansion of foraged woody species such as *D. cinerea* as the consequence of grazing pressure by livestock (Jacobs & Naiman, 2008) which might attract more giraffe herds (Fig. 10). More giraffe herds were encountered in less protected areas (i.e. 42 herds in Manyara Ranch, and 32 in Randilen WMA), than in the fully protected area (i.e. 31 Tarangire National Park) (Fig. 10), indicating a longer in stands of giraffe herds in less protected areas than fully protected areas. In this study, the rapidly expanding bush encroacher, *D. cinerea*, was only preferred in the less protected but not in fully protected areas owing to the slow rate of expansion by bush encroachers in an intact habitat as compared to mixed land used areas (Skarpe, 1990; Angassa & Oba, 2010; Bond, 2008).

Furthermore, browsing pressure from both livestock and wildlife can reduce intraspecific competition of foraged woody species, thus elevating woody plant species diversity, especially in human-influenced areas (Reyes *et al.,* 2010). The diversity of woody plant species in human-influenced landscapes ensures large herbivores with multiple food options and, therefore, giraffes might benefit from a variety of encroaching species fostered by the presence of livestock. This suggests the importance of community and privately owned lands in the efforts toward sustainable wildlife conservation while protecting the needs of the surrounding local pastoral communities (Duran, 2015). However, conservation initiatives in both protected and non-protected areas are challenged by increased human population inflicting habitat destruction, illegal hunting, land conversion, and bush encroachment (Muller *et al*., 2016). Hence, this emphasizes for the need to carefully monitor the availability of encroaching woody species to sustainably ensure that the quality and quantity of forage resources are available for the survival of giraffes and other browsing wildlife.

4.2.4 Spatial Scales and Resource Use

Study results did not support the prediction that local-scale forage selectivity would be expressed less strongly than at the landscape scale. However, giraffe forage preferences were sensitive to spatial scale changes (Bissonetie *et al.,* 1997; Anderson *et al.,* 2005). For example, *Combretum zheyeri* was preferred on a local scale during the dry season but not at the landscape level. The shift of forage preference as spatial scale increases is presumably associated with aggregates of habitat units within a heterogeneous landscape, which in turn affects resource availability estimates (Bissonette *et al.,* 1997. Furthermore, a landscape-scale embraces a diversity of habitats, thus capturing a wide range of resource use-availability attributes than would a small one (Bowyer *et al.*, 1996).

Based on existing assumptions, essential ecological processes operate at different spatial scales (Bissonette *et al.,* 1997; Mysterud *et al.,* 1999; Anderson *et al.,* 2005; Boyce, 2006). Therefore, changes in spatial scales influence the estimated proportions of available forage resources and, consequently, animal foraging patterns (Bissonette *et al.*, 1997). Besides, the accurate measure of forage use against availability requires estimates at narrower spatial scales (Arthur *et al.,* 1996; Johnson *et al.,* 2002; Manly *et al.,* 2002; Fortin *et al.,* 2005) taking into account resources available within the animal's home range. However, the use of one spatial scale of selection may limit the extrapolation of animal's foraging responses under varying environmental conditions, which eventually affect management decisions. Nevertheless, the multispatial scaled analyses for forage-procuring strategies that were used in this study provide a reliable means of comparing use versus available estimates at local and landscape scales of selection (Bissonetie e*t al.,* 1997;

Mysterud *et al.,* 1999; Anderson *et al.,* 2005; Fortin *et al.,* 2005; Boyce, 2006; Kotliar & Wiens, 2013), which eventually leads to judicious management decisions (Andren, 1994; Johnson *et al.*, 2002).

4.2.5 The Role of *Dichrostachys cinerea*

Giraffes exhibited a high and year-round preference for *Dichrostachys cinerea* at both local and landscape scales. Preferential use of *D. cinerea* is attributed to high-quality browse (Pellew, 1983; Mlambo *et al.,* 2004; Smith *et al.,* 2005; Tjelele *et al.,* 2014), and the gradual loss of their leaves followed by quick recovery (Fig. 12) upon the onset of the wet season (Sauer, 1983), which ensured giraffes with an almost constant supply of food throughout the year. Hence, giraffes might benefit from *D. cinerea* and vice versa as constant browsing, which might also stimulate the expansion of this woody species (Jacobs & Naiman, 2008). Most studies reported on selective giraffe use of species in the genus V*achellia* (Caister *et al.*, 2003; Sauer *et al.*, 1977; Mahenya *et al.,* 2016a; Pellew, 1984a) while only little has been published on the ecological importance of *D. cinerea* as forage species for giraffe (Sauer *et al.,* 1977). The lack of early reports on preferential use of *D. cinerea* in East African savannas could have resulted from its local distribution or sporadic manifestation in past years. With the current findings, managers will learn about the ecological functions of such shrub species as an imperative factor during rangeland management decisions. Based on the study findings, *Dichrostachys cinerea* is an important edible and potential forage species for giraffes in savannah rangeland systems. Therefore, this study findings contradict the notion that *Dichrostachys cinerea* in the savannah ecosystem is not beneficial by large wild herbivores (Richter, 2001; Mudzengi *et al.,* 2014; Kiffner *et al.,* 2017). However, a balance between woody and herbaceous cover can help ensure the availability of quality forages in large quantities for the full suite of savannah browsers and grazers.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study examined whether giraffe foraging behavior at different spatio-temporal scales is affected proportionally by forage species availability. Giraffes in the Tarangire Manyara Ecosystem selected a broad array of woody plant species but only a few plant species make up the bulk of the forage for giraffes. Forage selection by giraffes is influenced primarily by spatial and temporal changes in the quantities and, presumably, qualities of forage species at both local and landscape scales. Giraffes also showed a strong preference for the native shrub *D. cinerea* at both local and landscape scales. *Dichrostachys cinerea* is a fast-growing nutritive shrub, well adapted in the study area, palatable to giraffes, and resistant to strong browsing pressure, providing giraffes with a constant supply of this food resource throughout the year. The removal of this species for the purpose of maintaining grazing lawns for livestock might negatively impact browsing wildlife. Therefore, management that is focused on benefiting grazing livestock by removal of encroaching woody plant species may have unintended consequences on browsing species such as giraffes that feed extensively on these food resources. The results of this study provide rangeland managers with comprehensive baseline information on the current availability and usability of woody forage species in the Tarangire Manyara Ecosystem of Tanzania. Information presented in this study is useful for monitoring natural and human-influenced habitat changes for sustainable biodiversity conservation.

5.2 Recommendations

Study results showed that giraffes selected a broad array of woody plant species but only a few plant species make up the bulk of the forage for giraffes, and thus, the habitats that contain these preferred plants need to receive conservation attention. Giraffes shift their diet seasonally, both in strictly protected areas and in areas with multiple land uses. Hence, conservation areas should be managed to maintain habitat connectivity and heterogeneity that guarantee the availability of forages for giraffes in both dry and wet seasons. The results also suggest that browsing wildlife species such as giraffes may be adversely affected by the removal of *D. cinerea* from rangelands and that managing for grazing livestock only could negatively impact particularly browsing wildlife on mixed-use lands. This study, therefore, recommends for the rangeland management scheme that would ensure a balance between woody and herbaceous cover which guarantees the availability of quality and quantity food for the full suite of savannah browsers and grazers. The recent study was limited to forage observations collected for only four months, hence, longer-term resource assessments are recommended to understand how strongly foraging preferences and avoidances vary with scales of selections and over several seasons. Further, the assessment of the seasonal nutritional content of available forages is strongly recommended to complement the findings of this study and to understand the mechanisms of selection better.

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APPENDICES

Appendix 1: Woody plant species encountered in both random strip transects following giraffe foraging patch selection and along systematic point transects in Tarangire Manyara Ecosystem, Tanzania, in 2019

SN	Scientific name	Common Names	Family
1	*Abutilon mauritinum*	Country mallow, Velvetleaf	Malvaceae
2	*Acalypha fructosa*	Birch-leaved cat tail	Euphorbiaceae
3	*Adansonia digitata*	Baobab	Bombacaceae
4	*Albizia amara*	Bitter Albizia	Fabaceae
5	*Albizia athelmintica*	Worm-Cure Albizia	Fabaceae
6	*Albizia harveyi*	Sickle-leaved albizia	Fabaceae
7	*Annona senegalensis,*	Wild custard apple	Annonaceae
8	*Aspagrus africana*	African asparagus, Asparagus fern	Asparagaceae
9	*Azanza garckeana*	Azanza, Slime-apple, Snot apple	Malvaceae
10	*Balanites aegyptiaca*	Desert date	Balanitaceae
11	*Balanites gibra*	Torchwood	Balanitaceae
12	*Bauhinia sp*	Hawaiian orchid tree, Butterfly tree	Fabaceae
13	*Boscia mosambisensis*	Broad-leaved shepherds tree	Capparaceae
14	*Boswelia negleta*	Black Frankincense	Burseraceae
15	*Cadaba farinosa*	Mvunja-vumo,Kibilazimwitu (Swahili)	Capparaceae
16	*Capparis fascularis*	Zizag caper-bush	Capparaceae
17	*Capparis sepiaria*	Wild Caper Bush	Capparaceae
18	*Capparis tomentosa*	Woolly caper-bush, wait a minute	Capparaceae
19	*Carrisa spinorum*	Conkerberry	Apocynaceae
20	*Cassia abbreviata*	Long-tail cassia	Fabaceae
21	*Catenarugum spinosa*	Mountain Pomegranate	Rubiaceae
22	*Catunaregam taylorii*	-	Rubiaceae
23	*Clerodendrum mycoides*	Glory bower, Bag flower	Lamiaceae
24	*Combretum molle*	Velvet bush willow	Combretaceae
25	*Combretum schumanii*	combretum (Mlama)	Combretaceae
26	*Combretum schumannii*	Bushwillows	Combretaceae
27	*Combretum zheyeri*	Large-fruited bushwillow	Combretaceae
28	*Commiphora mossambicensis*	Pepper-leaved corkwood	Burseraceae
29	*Commiphora africana*	African myrrh	Burseraceae
30	*Commiphora baranensis*	Sand Commiphora	Burseraceae
31	*Commiphora eminii*	Corkwood, Commiphora	Burseraceae
32	*Commiphora madagascariensis*	-	Burseraceae

SN	Scientific name	Common Names	Family
33	*Commiphora schimperii*	Glossy-leaved corkwood	Burseraceae
34	*Commiphora tenuipetiolata*	Satin-bark corkwood	Burseraceae
35	*Coordia monoica*	Sandpaper saucer-berry, Snot berry	Boraginaceae
36	*Cordia crenata*	-	Boraginaceae
37	*Cordia geneta*	-	Boraginaceae
38	*Cordia sinensis*	Grey-leaved saucer berry	Boraginaceae
39	*Croton dichogamus*	Rush foil and Croton	Euphorbiaceae
40	*Dalbergia melanoxylon*	African black woody/African ebony	Fabaceae
41	*Dalbergia nitidula*	Glossy flat-bean	Fabaceae
42	*Dichrostachys cinerea*	Sicklebush, Marabou thorn	Fabaceae
43	*Eheretia amoena*	Puzzle bush, Sandpaper	Boraginaceae.
44	*Euphorbia candelabrum*	candelabra tree	Euphorbiaceae
45	*Euphorbia cuniata*	-	Euphorbiaceae
46	*Euphorbia nyikae*	Spurge	Euphorbiaceae
47	*Ficus natarensis*	Natal fig	Moraceae
48	*Ficus sycomorus*	Sycamore fig or the Fig-mulberry	Moraceae
49	*Flaggea virosa*	Bushweed	Phyllanthaceae
50	*Gardenia tenufolia*	Cape jasmine, Cape jessamine,	Rubiaceae
51	*Gnidia emini*	saffron bush	Thymelaeaceae
52	*Grewia bicolor*	Bastered brady bush	Tiliaceae
53	*Grewia lasiocarpa*	Forest raisin	Tiliaceae
54	*Grewia occidentalis*	Cross-berry	Tiliaceae
55	*Grewia robusta*	Karoo cross-berry	Tiliaceae
56	*Grewia tenax*	Small-leaved cross-berry	Tiliaceae
57	*Grewia villosa*	Mallow raisin	Tiliaceae
58	*Haephaene petersiana*	Wild date palm	Plmae
59	*Harrisonia abyssinica*	-	Rutaceae
60	*Hoslundia opposita*	Orange bird berry, Butter-berry	Labiatae
61	*Indigofera errector*	Bengal Indigo	Fabaceae
62	*Ipomea hildebrandtii*	Morning glory, Sweet potato	Convolvulaceae
63	*Kigelia africana*	Sausage tree	Bignoniaceae
64	*Lanchocarpus eriocalyx*	Broad lance-pod	Papilionaceae
65	*Lannea discolor*	Live-long	Anacardiaceae
66	*Lannea edulis*	Wild grape	Anacardiaceae
67	*Lannea schimperi*	-	Anacardiaceae
68	*Lannea schweinfurthii*	False-marula	Anacardiaceae
69	*Lannea triphylla*	-	Anacardiaceae
70	*Maerua clasifolia*	-	Capparaceae
71	*Maerua decumbens*	Blue bush-cherry	Capparaceae

SN	Scientific name	Common Names	Family
72	*Maerua triphylla*	Small bead-bean	Capparaceae
73	*Markamia obtusifolia*	Golden Bell-bean	Bignoniaceae
74	*Markamia platycalyx*	Nile trumpet or Siala tree	Bignoniaceae
75	*Markhamia lutea*	Bell bean tree	Bignoniaceae
76	*Markhamia zanzibar*	Bell bean tree or maroon bell-bean	Bignoniaceae
77	*Mytenus senegalensis*	Spike thorn	Celastraceae
78	*Ochna holstii*	Common forest ochna, Red ironwood	Ochnaceae
79	*Ochna pulchra*	Lekkerbreek, Peeling plane	Ochnaceae
80	*Opilia amantecea*	-	Opiliaceae
81	*Ormocarpum kirkii*	Caterpillar bush	Fabaceae
82	*Ozoroa isignis*	African resin tree	Anacardiaceae
83	*Ozoroa pulcherrima*	Lady's tears	Anacardiaceae
84	*Palveta schumanniana*	Poison bride's bush	Rubiaceae
85	*Pluchea ovalis*	-	Compositae
86	*Rhus natalensis*	Natal karree, Natal rhus	Anacardiaceae
87	*Salvadora persica*	Mastered tree/ Tooth-brush tree	Salvadoraceae
88	*Sclerocalya birea*	Marula	Anacardiaceae
89	*Sclopia zeyheri*	Thorn pear	Olacaceae
90	*Stereospermum kunthianum*	Pink jacaranda	Bignoniaceae
91	*Strychnos potatorum*	Clearing-nut tree	Loganiaceae
92	*Strychnos spinosa*	Green monkey orange	Loganiaceae
93	*Terminalia brownii*	Mururuku (Kamba)	Combretaceae
94	*Terminalia indica*	Maidera mahogany	Fabaceae
95	*Terminalia siricea*	Silver cluster-leaf, Vaalboom	Combretaceae
96	*Terminalia spinosa*	Spiny terminalia	Combretaceae
97	*Tetradenia riparia*	Ginger Bush	Lamiaceae
98	*Thylachium africanun*	Cucumber bush	Capparaceae
99	*Trichilia ematica*	Natal mahogany	Meliaceae
100	*Vachellia brevispica*	Wait-a-bit thorn	Fabaceae
101	*Vachellia (Faidherbia) albida*	A. mossambicensi,Ana-tree	Fabaceae
102	*Vachellia drepanolobium*	Whistling thorn	Fabaceae
103	*Vachellia hockii*	White thorn acacia, Shittim wood	Fabaceae
104	*Vachellia kirkii*	Kimwea or Mwea (Kamba)	Fabaceae
105	*Vachellia mellifera*	Blackthorn and Swarthaak	Mimosaceae
106	*Vachellia nilotica*	Gum arabic tree,Thorny acacia	Fabaceae
107	*Vachellia nubica*	White thorn acacia	Fabaceae
108	*Vachellia robusta*	Ankle thorn, River thorn	Fabaceae
109	*Vachellia senegal*	Gum Arabic	Mimosoideae

SN	Scientific name	Common Names	Family
110	*Vachellia seyal*	Red acacia (Shittah tree)	Fabaceae
111	*Vachellia sieberiana*	Paperbark thorn or Paperbark acacia	Fabaceae
112	*Vachellia tortilis*	Umbrella thorn	Mimosoideae
113	*Vachellia xanthophloea*	Fever tree	Fabaceae
114	*Venonia cinerea*	Tagulinau , Dandotapala, Sadodi	Asteraceae
115	*Vitex frruginea*	Plum fingerleaf	Verbenaceae
116	*Ximenia caffra*	Wild olive, Wild lime; Tallow nut	Olacaceae
117	*Zanthophylum chalybeum*	Knob wood	Rutaceae
118	*Ziziphus mucrunata*	Buffalo thorn	Rhamnaceae

Appendix 2: Giraffe (*Giraffa camelopardalis tippelskirchi*) local-scale forage selection ratios (Ŵ), and their Bonferroni confidence intervals (CI Ŵ), and the seasonal selection differences for 38 woody plant species in the Tarangire Manyara Ecosystem, for the wet and dry season in the year 2019

Woody species	Local Selection (W)			Confidence Intervals (CI Ŵ)						Δseasonal selection
	Yearly	Dry	Wet	Yearly		Dry		Wet		
				Lower	High	Lower	High	Lower	High	p-values
Adansonia digitata	0.00	0.01	0.00	**-0.01**	**0.01**	**-0.04**	**0.07**	**0.00**	**0.00**	0.985
Albizia anthelmintica	0.21	2.08	0.06	**0.02**	**0.4**	**0.13**	**4.02**	**-0.05**	**0.16**	0.040*
Balanites aegyptiaca	1.04	0.80	1.26	**0.84**	**1.23**	**0.56**	**1.03**	**0.94**	**1.58**	0.574
Boscia mosambisensis	0.07	0.36	0.00	**-0.19**	**0.33**	**-0.9**	**1.62**	**0.00**	**0.00**	0.693
Boswelia negleta	-	-	-	-	-	-	-	-	-	-
Capparis fascularis	0.16	0.21	0.10	**0.04**	**0.29**	**0.04**	**0.39**	**-0.07**	**0.26**	0.879
Capparis sepiaria	-	-	-	-	-	-	-	-	-	-
Carrisa spinorum	0.81	0.81	-	**-0.06**	**1.67**	**0.01**	**1.60**	-	-	-
Combretum molle	0.39	0.51	0.00	**-0.05**	**0.83**	**-0.02**	**1.04**	**0.00**	**0.00**	0.542
Combretum zeyheri	2.55	2.70	0.00	**1.47***	**3.63***	**1.65***	**3.75***	**0.00**	**0.00**	0.005*
Commiphora africana	0.02	0.00	0.06	**-0.04**	**0.09**	**0.00**	**0.00**	**-0.14**	**0.27**	0.936
Commiphora schimperii	0.26	0.17	0.35	**0.10**	**0.43**	**-0.01**	**0.34**	**0.07**	**0.63**	0.818
Cordia monoica	0.27	-	0.27	**-0.06**	**0.60**	-	-	**-0.09**	**0.63**	-
Dalbergia melanoxylon	0.67	0.48	1.06	**0.49**	**0.85**	**0.30**	**0.65**	**0.63**	**1.48**	0.486
Dichrostachys cinerea	1.59	1.87	1.24	**1.44***	**1.74***	**1.67***	**2.07***	**1.01***	**1.47***	9.9E-08*
Euphobia candelabrum	0.19	-	0.19	**-0.28**	**0.66**	-	-	**-0.33**	**0.70**	-
Ficus -natarensis	-	-	-	-	-	-	-	-	-	-
Flaggea virosa	0.06	0.00	0.3	**-0.10**	**0.22**	**0.00**	**0.00**	**-0.53**	**1.12**	0.737
Gardenia tenufolia	1.05	0.00	-	**-0.53**	**2.63**	**0.00**	**0.00**	-	-	-
Harrisonia abyssinica	0.72	1.19	0.00	**0.20**	**1.25**	**0.39**	**1.99**	**0.00**	**0.00**	0.182
Kigelia africana	0.07	0.02	0.14	**-0.06**	**0.20**	**-0.07**	**0.11**	**-0.17**	**0.44**	0.886
Lanchocarpus eriocalyx	0.51	0.58	0.00	**0.14**	**0.87**	**0.19**	**0.97**	**0.00**	**0.00**	0.478
Lannea edulis	0.14	0.00	0.42	**-0.15**	**0.44**	**0.00**	**0.00**	**-0.53**	**1.36**	0.64
Maerua triphylla	0.72	1.57	0.3	**0.47**	**0.97**	**0.97**	**2.16**	**0.08**	**0.51**	0.144
Ozoroa insignis	0.88	0.00	1.28	**-0.58**	**2.35**	**0.00**	**0.00**	**-1.05**	**3.61**	0.195

Woody species	Local Selection (W)			Confidence Intervals (CI Ŵ)						∆seasonal selection
	Yearly	Dry	Wet	Yearly		Dry		Wet		
				Lower	High	Lower	High	Lower	High	p-values
Salvadora persica	0.16	0.63	0.05	**-0.04**	**0.35**	**-0.23**	**1.5**	**-0.08**	**0.19**	0.511
Scolopia zeyheri	1.11	1.11	-	**-1.41**	**3.64**	**-1.23**	**3.46**	-	-	-
Strychnos potatorum	1.54	3.11	1.05	**0.97**	**2.10**	**1.58***	**4.64***	**0.46**	**1.63**	0.034*
Vachellia drepanolobium	1.38	1.13	1.59	**1.15***	**1.61***	**0.84**	**1.42**	**1.22***	**1.96***	0.581
Vachellia kirkii	2.14	1.76	2.21	**1.63***	**2.66***	**0.64**	**2.88**	**1.60***	**2.83***	0.623
Vachellia mellifera	1.34	1.55	1.07	**1.18***	**1.50***	**1.35***	**1.75***	**0.83**	**1.31**	0.546
Vachellia nilotica	0.19	0.22	0.05	**0.04**	**0.34**	**0.06**	**0.38**	**-0.16**	**0.26**	0.828
Vachellia senegal	0.09	0	0.16	**-0.04**	**0.22**	**0.00**	**0.00**	**-0.09**	**0.41**	0.837
Vachellia seyal	0.11	0	-	**-0.16**	**0.38**	**0.00**	**0.00**	-	-	-
Vachellia tortilis	1.49	0.97	1.99	**1.36***	**1.63***	**0.82***	**1.12***	**1.77***	**2.22***	0.199
Vachellia xanthophloea	0.26	0.00	-	**-0.48**	**1.01**	**0.00**	**0.00**	-	-	-
Ximenia caffra	0.30	0.24	0.55	**-0.24**	**0.83**	**-0.26**	**0.73**	**-1.28**	**2.38**	0.742
Ziziphus mucronata	1.26	1.26	-	**0.36**	**2.17**	**0.43**	**2.1**	-	-	-

Note: The selection coefficient is significant if the confidence interval for Ŵ does not contain the value 1. If CI Ŵ > 1, then the species was significantly preferred (green highlighted text), if CI Ŵ < 1, then it was significantly avoided (red text) by giraffes, if CI Ŵ includes 1, then the woody species was used in proportion to its availability, If $p < (0.05)^*$ = significant seasonal difference in selection. Dashes indicate insufficient data

Appendix 3: Giraffe (*Giraffa camelopardalis tippelskirchi*) landscape-scale forage selection ratios (Ŵ), and their Bonferroni confidence intervals (CI Ŵ), and seasonal selection differences for 38 woody plant species in the Tarangire Manyara Ecosystem, 2019

Woody species	Landscape Selection (W)			Confidence Intervals (CI Ŵ)						Δseasonal selection
	Year	Dry	Wet	Year		Dry		Wet		
				Lower	High	Lower	High	Lower	High	p-values
Adansonia digitata	0.00	0.01	0.00	-0.01	0.02	-0.02	0.04	0.00	0.00	0.446
Albizia anthelmintica	0.09	0.13	0.04	0.01	0.16	0.01	0.25	-0.04	0.12	0.06
Balanites aegyptiaca	2.15	1.56	2.73	1.74*	2.55*	1.10*	2.01*	2.04*	3.43*	<0.001*
Boscia mosambisensis	0.12	0.24	0.00	-0.33	0.57	-0.60	1.08	0.00	0.00	0.366
Boswelia negleta	-	-	-	-	-	-	-	-	-	-
Capparis fascularis	0.53	0.80	0.25	0.12	0.93	0.15	1.46	-0.18	0.69	0.033*
Capparis sepiaria	-	-	-	-	-	-	-	-	-	-
Carrisa spinorum	0.56	1.12	0.00	-0.04	1.15	0.01	2.22	0.00	0.00	0.003*
Combretum molle	0.09	0.19	0.00	-0.01	0.2	-0.01	0.38	0.00	0.00	0.004*
Combretum zheyeri	0.37	0.74	0.00	0.21	0.52	0.45	1.02	0.00	0.00	<0.001*
Commiphora africana	0.01	0.00	0.03	-0.03	0.05	0.00	0.00	-0.06	0.11	0.345
Commiphora schimperii	0.23	0.13	0.32	0.09	0.37	-0.01	0.27	0.06	0.58	0.049*
Cordia monoica	0.31	0.00	0.62	-0.06	0.69	0.00	0.00	-0.2	1.44	0.020*
Dalbergia melanoxylon	0.47	0.44	0.49	0.34	0.59	0.28	0.60	0.29	0.69	0.572
Dichrostachys cinerea	2.72	3.54	1.91	2.46*	2.99*	3.17*	3.92*	1.55*	2.26*	<0.001*
Euphobia candelabrum	0.04	0.00	0.08	-0.06	0.14	0.00	0.00	-0.14	0.3	0.252
Ficus natarensis	8.10	16.19	0.00	1.11*	15.08*	3.28*	29.11*	0.00	0.00	0.000*
Flaggea virosa	0.12	0.00	0.25	-0.19	0.44	0.00	0.00	-0.45	0.95	0.261
Gardenia tenufolia	10.39	0.00	20.78	-5.22	25.99	0.00	0.00	-13.38	54.93	0.06
Harrisonia abyssinica	0.88	1.77	0.00	0.24	1.53	0.57	2.96	0.00	0.00	<0.001*
Kigelia africana	0.06	0.02	0.11	-0.06	0.18	-0.07	0.12	-0.13	0.34	0.308
Lanchocarpus eriocalyx	0.26	0.52	0.00	0.07	0.45	0.17	0.87	0.00	0.00	<0.001*
Lannea edulis	0.06	0.00	0.11	-0.06	0.17	0.00	0.00	-0.14	0.36	0.167
Maerua triphylla	1.62	2.36	0.89	1.06*	2.19*	1.47*	3.25*	0.24	1.55	0.000*
Ozoroa insignis	0.15	0.00	0.31	-0.10	0.41	0.00	0.00	-0.25	0.87	0.088

Woody species	Landscape Selection (W)			Confidence Intervals (CI Ŵ)						Δseasonal selection
	Year	Dry	Wet	Year		Dry		Wet		
				Lower	High	Lower	High	Lower	High	p-values
Salvadora persica	1.57	2.28	0.85	**-0.39**	**3.53**	**-0.82**	**5.38**	**-1.39**	**3.09**	0.24
Scolopia zheyeri	-	-	-	-	-	-	-	-	-	-
Strychnos potatorum	1.90	1.83	1.97	**1.20***	**2.60***	**0.93**	**2.73**	**0.87**	**3.07**	0.756
Vachellia drepanolobium	3.39	2.55	4.24	**2.82***	**3.96***	**1.89***	**3.21***	**3.26***	**5.21***	<0.001*
Vachellia kirkii	1.32	0.34	2.30	**1.00***	**1.64***	**0.12**	**0.55**	**1.66***	**2.94***	<0.001*
Vachellia mellifera	2.59	3.42	1.77	**2.29***	**2.90***	**2.97***	**3.86***	**1.37***	**2.17***	<0.001*
Vachellia nilotica	0.70	1.34	0.06	**0.15**	**1.24**	**0.34**	**2.33**	**-0.19**	**0.3**	0.000*
Vachellia senegalensis	0.15	0.00	0.31	**-0.06**	**0.37**	**0.00**	**0.00**	**-0.17**	**0.78**	0.047*
Vachellia seyal	-	-	-	-	-	-	-	-	-	-
Vachellia tortilis	2.09	1.33	2.84	**1.90***	**2.27***	**1.12***	**1.54***	**2.53***	**3.16***	<0.001*
Vachellia xanthophloea	-	-	-	-	-	-	-	-	-	-
Ximenia caffra	0.25	0.33	0.18	**-0.21**	**0.72**	**-0.36**	**1.01**	**-0.42**	**0.78**	0.615
Ziziphus mucrunata	0.67	1.34	0.00	**0.19**	**1.14**	**0.46**	**2.22**	**0.00**	**0.00**	0.000*

Note: The selection coefficient is significant if the confidence interval for Ŵ does not contain the value 1. If CI Ŵ > 1, then preferred (green highlighted text), if CI Ŵ < 1, then avoided (red text), if CI Ŵ includes 1, then used in proportion to availability. Note: Highlighted green* = significantly preferred, Bold = not significant, Red = significantly avoided, * = significant seasonal difference. Zeros or missing values were obtained if either foraged or available proportions were zero

Appendix 4: Giraffe scale based selection differences for 38 woody plant species in the Tarangire Manyara Ecosystem, in 2019

Woody species	Local Selection	Landscape Selection	∆scale selection
Dichrostachys cinerea	1.59	2.72	<0.001**
Vachellia tortilis	1.49	2.09	<0.001**
Vachellia mellifera	1.34	2.59	<0.001**
Vachellia drepanolobium	1.38	3.39	<0.001**
Balanites aegyptiaca	1.04	2.15	<0.001**
Vachellia kirkii	2.14	1.32	<0.001**
Dalbergia melanoxylon	0.67	0.47	0.005*
Maerua triphylla	0.72	1.62	<0.001**
Ziziphus mucronata	1.26	0.67	0.070
Vachellia nilotica	0.19	0.70	0.008*
Strychnos potatorum	1.54	1.90	0.209
Commiphora schimperii	0.26	0.23	0.574
Combretum zheyeri	2.55	0.37	<0.001**
Lanchocarpus eriocalyx	0.51	0.26	0.066
Albizia anthelmintica	0.21	0.09	0.053
Capparis fascularis	0.16	0.53	0.010*
Carrisa spinorum	0.81	0.56	0.455
Boswelia negleta	-	`	-
Cordia monoica	0.27	0.31	0.806
Combretum molle	0.39	0.09	0.040*
Gardenia tenufolia	1.05	10.39	0.065
Vachellia senegalensis	0.09	0.15	0.439
Salvadora persica	0.16	1.57	0.028*
Euphorbia candelabrum	0.19	0.04	0.334
Ficus natarensis	-	8.10	-
Harrisonia abyssinica	0.72	0.88	0.547
Vachellia xanthophloea	0.26	-	-
Kigelia africana	0.07	0.06	0.920

Woody species	**Local Selection**	**Landscape Selection**	**∆scale selection**
Lannea edulis	0.14	0.05	0.376
Scolopia zheyeri	1.11	-	-
Ximenia africana	0.30	0.25	0.851
Vachellia seyal	0.11	-	-
Adansonia digitata	0.00	0.00	0.870
Boscia mosambisensis	0.07	0.12	0.757
Commiphora africana	0.02	0.01	0.717
Capparis sepiaria	-	-	-
Flaggea virosa	0.06	0.12	0.586
Ozoroa insignis	0.88	0.15	0.127

Note: Selection ratios are based on Manly et al. (2002). If p < (0.05)*, then significantly preferred/avoided

RESEARCH OUTPUTS

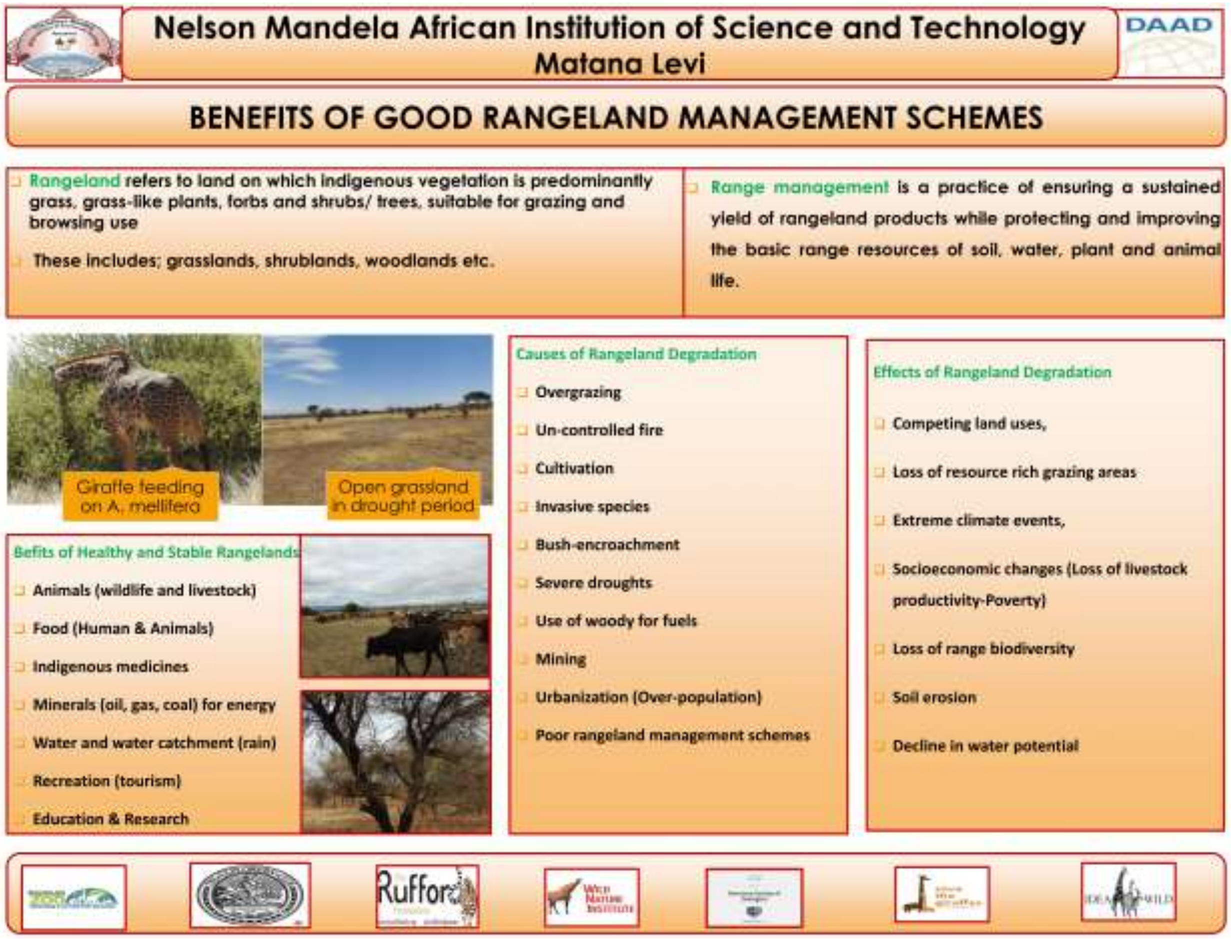
Output One: A research Paper

Levi, M., Lee, D. E., Bond, M. L., & Treydte, A. C. (2022). Forage selection by Masai giraffes (*Giraffa camelopardalis tippelskirchi*) at multiple spatial scales. *Journal of Mammalogy*, *XX*(X):1–8.

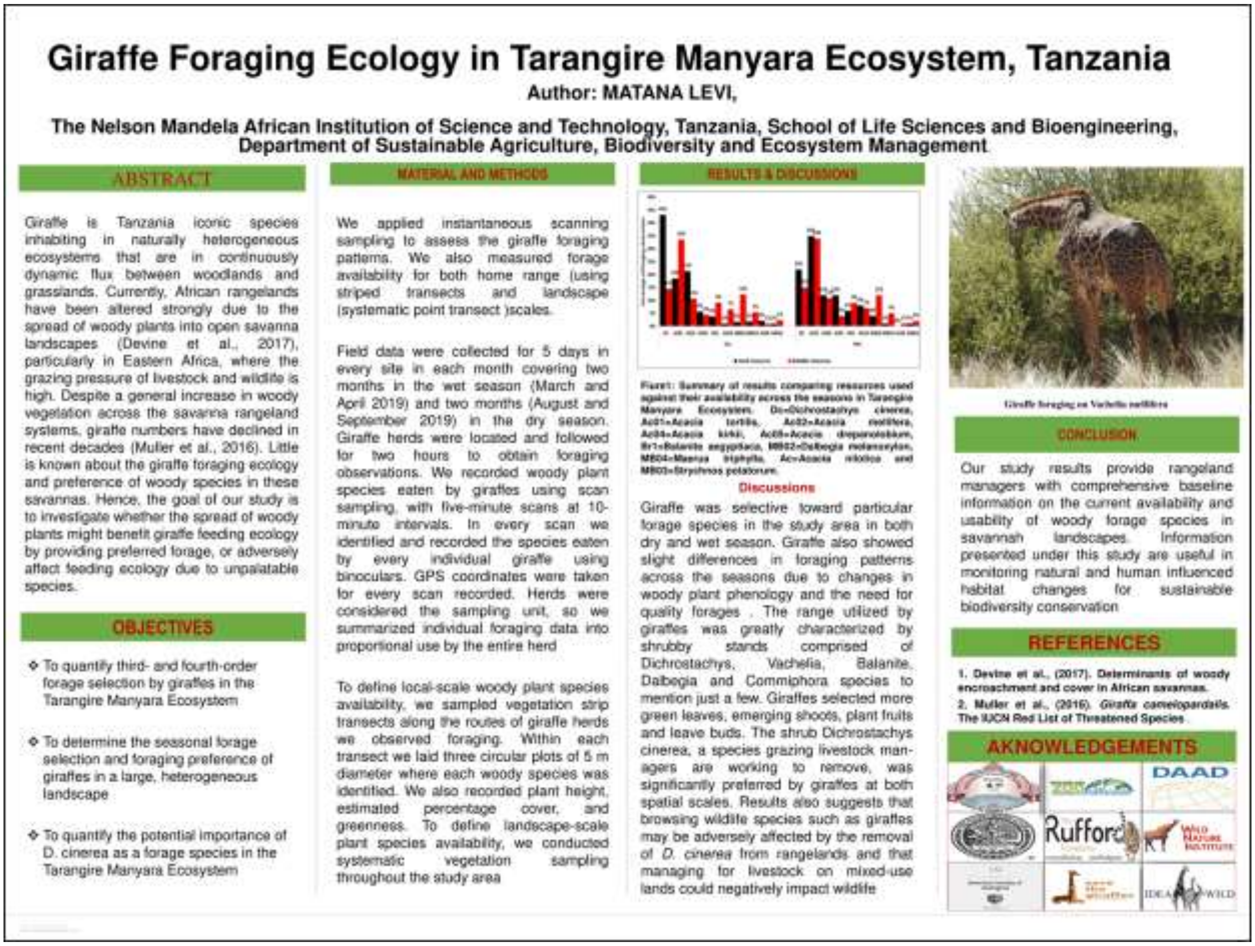
Output Two: Press Release Published in Phys.org News

Bush-encroaching sickle bush is preferred food of giraffes. https://phys.org/news/2022-03-bush-encroaching-sickle-bush-food-giraffes.html. Retrieved 18 March 2022.

Output Three: 2 Poster Presentation



Poster1: Poster presented at Monduli district and in primary and secondary schools around the Tarangire Manyara Ecosystem, Tanzania



Poster2: Poster presented at Monduli district and in primary and secondary schools around the Tarangire Manyara Ecosystem, Tanzania.