IS IT GREENER ON THE OTHER SIDE, OR ARE ELEPHANTS JUST ON A HIGH?

A COMPARISON OF SCALE, SEX AND SEASON FOR GREENNESS AND ELEVATION

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Declaration

I hereby declare that this research report is my own, unaided work except where acknowledged. It is being submitted in partial fulfilment of the requirements for the Bachelor of Science with Honours degree in the University of the Witwatersrand, Johannesburg. It has not been submitted for any degree or examination in any other university.

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Azhar Rajah

____________day of________________2008

“Proud” a collared male elephant, his locations were among those analyzed in my study.

RESEARCH CONCEPTUALIZATION

The Problem Statement:

Elephant foraging preferences can be investigated using elephant locations and remote sensing of vegetation (i.e., the normalized difference vegetation index- NDVI). No previous studies using NDVI have considered elephant habitat selection over dry and wet seasons for both sexes. All surveyed elephant habitat selection studies have discontinuous sampling periods (data gaps) and none of these reviewed studies have addressed habitat selection at more than one scale.

Elephants associations with vegetation in the KNP and adjacent private reserves were studied for the period November 2005- November 2007. Muriwa and Skidmore (2005) used NDVI to explain differences in elephant location between agricultural and savanna vegetation types. My study analyzes associations with NDVI within the savanna vegetation type. Also Chamaille-Jammes *et al.*, (2007) and Smit *et al.*, (2007)'s studies were focused on water availability with NDVI used as an explanatory variable.

The Purpose Statement:

The purpose of this research was to see if elephant locations are associated with vegetation greenness (NDVI) and the covariate elevation based on a digital elevation model (DEM). These associations were compared between different seasons and sexes, at different spatial and temporal scales to explore elephant habitat selection patterns.

Research Questions:

1. Are elephant locations associated with NDVI?
2. At what scale is this association manifested?
3. Are associations between elephant locations and NDVI more apparent after accounting for elevation (covariant)?
4. How do these patterns related to elephant habitat selection?

RESEARCH REPORT

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ABSTRACT:

It is important that the scale at which patterns of foraging ecology are studied corresponds to the scale of the process. It is also important to understand how generalist herbivores select for forage at different scales. In my study, associations with vegetation greenness (NDVI) and elevation (DEM) were compared within the 16-day home range and between the 16-day home range and the seasonal home range, to investigate patterns of elephant habitat selection. Most individuals showed no evidence of an association with NDVI. Most of those elephants that showed evidence of an association with NDVI were associated with lower values (i.e., lower vegetation quality or quantity). More elephants had evidence of an influence by both NDVI and DEM at the 16-day scale than at the seasonal scale. More males had evidence of an association with NDVI and DEM (covariate) in the dry season than in the wet season. Most elephants had evidence of an association with elevations that were higher than what was randomly available. Mechanisms that lead to selection of higher elevations warrant further investigation.

INTRODUCTION:

Understanding the processes that underlie patterns in nature is an important component of ecology. However, these processes usually occur at scales different to that at which they are observed by researchers (Levin, 1992). This is because different species perceive their environments differently and researchers impose an observational bias (Levin, 1992). Therefore, it is important that studies of habitat selection look at interactions at varying spatial and temporal scales (Orians and Wittenberger, 1991; Boyce, 2006). Foraging theory being a component of resource selection should also explain variation in selection with scale (Senft *et al.*, 1987). The distribution of an animal's food is a major determinant of habitat selection (Orians and Wittenberger, 1991); strongly influencing the animal's spatial distribution patterns. This resultant "utilization distribution" can be described using home range methods to analyze response characteristics of the home range (Anderson, 1982).

Remote sensing and Geographic Information Systems (GIS) are commonly used in wildlife habitat use studies (Verlinden and Masogo, 1997; Osborne *et al*., 2001; Musiega and Kazadi, 2004). The normalized difference vegetation index (NDVI) is a remotely sensed measure of the greenness of the Earth monitored by satellite imagery (Reed *et al.*, 1994; Pettorelli *et al.*, 2005). These NDVI values give an indication of the spatial and temporal variability in the quantity (biomass) and quality (green up) of vegetation (Huete *et al.*, 2002; Pettorelli *et al.*, 2005; Van Bommel *et al.*, 2006). Furthermore, there is good correspondence between Moderate Resolution Image Spectrometer (MODIS) NDVI values and above-ground vegetation biomass in savannas (Huete *et al.*, 2002). The normalized difference vegetation index has shown close relationships with animal habitat selection (Pettorelli *et al.*, 2005; Van Bommel *et al.*, 2006), and it can be an accurate predictor of herbivore locations (Musiega and Kazadi, 2004; Mueller *et al.*, 2007).

The utilization distribution of the African elephant (*Loxodonta africana*) can be influenced by a number of factors. Elephants select habitats based on the heterogeneity of the landscape (Grainger *et al.*, 2005; Murwira and Skidmore, 2005), water availability (Chamaille-Jammes *et al.*, 2007), nutrient distribution (Weir, 1972), human distribution (Harris *et al.*, 2008), vegetation structure (Riginos and Grace, 2008) and vegetation greenness (Murwira and Skidmore, 2005; Chamaille-Jammes *et al.*, 2007; Smit *et al.*, 2007).The African elephant is adapted to a large variety of environments (Laursen and Bekoff, 1978). Despite this generalist strategy, NDVI explains a substantial proportion of variability in patterns of their distribution (Murwira and Skidmore, 2005, Chamaille-Jammes *et al.*, 2007; Smit *et al.*, 2007), this could confirm the finding of Babaasa (2000), that the ranging patterns of elephants are linked to their feeding behaviour. Elephants tend to select areas with high vegetation cover if it is close to water (Chamaille-Jammes *et al.*, 2007; Harris *et al.*, 2008). Specifically, areas with high tree densities are favoured (Riginos and Grace, 2008).

The distribution patterns of elephants also vary with factors such as season and sex. Elephant have complex social interactions that influence habitat selection and consequently their location (Couzin, 2006). For example, sexual segregation (Laursen and Bekoff, 1978; Smit *et al.*, 2007) could arise because males and females select habitats based on different resource acquisition requirements due to their different reproductive needs (Grainger *et al.*, 2005). Females and sub-adults have smaller body sizes and different nutritional requirements than males, such as increased water requirements during lactation and an increased requirement for vegetation quality (Stokke and du Toit, 2002). Conversly, males select for areas containing higher forage biomass because they are tolerant of a larger range of vegetation quality which allows them to occupy larger home ranges (Shannon *et al.*, 2006; Smit *et al.*, 2007). Studies have also found that elephant groups use different vegetation types in the different seasons (Babaasa, 2000; Shannon *et al.*, 2006) and that the wet season home range is smaller than the dry season home range for elephants in the Pongola Game Reserve (Shannon *et al.*, 2006). Grainger *et al.* (2005) did not find a relationship between the elephant home range sizes for sex and season however there were differences found between sexes for landscape heterogeneity.

In my study, the influence of vegetation greenness on elephant habitat use was explored. Studies incorporating NDVI in the habitat selection of elephants have been relatively recent (Table 1), and few have looked at habitat selection over dry and wet seasons for both sexes. Of the previous habitat selection studies of elephants in the Kruger National Park (KNP) (Table1), only Smit *et al.*, (2007) looked at NDVI, but their primary focus was on the role of water availability. None of the studies reviewed have done analyses at more than one scale. Many studies also lack a seasonal comparison because of the relatively poor temporal resolution of the data used. For example, studies in Table 1 have sampling gaps and, thus, data represents a discontinuous representation of available resources throughout the year. However, the current study used (global positioning system) GPS telemetry to provide continuous tracking of several individuals over both seasons for more than a year. This fine temporal resolution of the data with a relatively large number of replicates (15 elephants) makes the current study an improvement on previous studies. My study aims to look at the influence of vegetation measured by NDVI, on elephant location between different seasons and sexes at different scales. Along with greenness, the role of elevation was assessed as an explanatory variable for patterns of association with NDVI. Understanding the influences of NDVI and DEM can facilitate a better understanding of the processes behind habitat selection.

Two hypotheses were proposed. Firstly because large herbivores' food sources are generally dispersed over large areas (Senft *et al.*, 1987); selection was predicted to occur primarily at the larger scale. Once that selection has occurred, generalist foraging was predicted to be non selective within the small spatial scale. Therefore it was assumed that there would be no evidence of an association within the 16-day home ranges. The second hypothesis was that when comparing between the 16-day and seasonal home range, it was expected that the elephants will not be associated with NDVI in the dry season due to selection for alternative resources during this stressful period. Instead, they will be associated with greener areas during the wet season because locations will be based primarily on vegetation when water is not limiting.

METHODS AND MATERIALS

STUDY SITE:

The study site included the KNP and the adjacent private reserves to the west of the KNP (Umbabat, Balule, Manyeleti, Letaba, Sabisand, Timbavati and Klaserie). The private reserves were once separated from the KNP by fences, but those fences have been removed such that there are no longer barriers to animal movement.

The KNP is situated in the northeastern lowveld of South Africa bordering Mozambique and Zimbabwe (Fig. 1). The KNP has a tropical climate in the north and a temperate climate in the south, with a rainfall gradient increasing from 400mm to 600mm from north to south (du Toit *et al.*, 2003). The western side of the KNP has granitic soils and the eastern side has basaltic soils (du Toit *et al.*, 2003). The KNP is mainly composed of arid to sub-arid wooded savanna vegetation, which is composed of a tree and grass mix that is spatially and temporally variable (Scholes and Archer, 1997; du Toit *et al.*, 2003). Vegetation communities within the KNP are influenced by herbivory and fire-related impacts (Cole, 1986). The vegetation is typical for catenas, having a predictable sequence of vegetation and soil with changes in position on the hillslope (Cole, 1986; Scholes and Walker, 1993).

Elephants are mixed feeders, consuming varying proportions of grass and browse (Cordon *et al.*, 2006). Elephant foraging has a negative impact on woody vegetation and, thus, plays an important role in the maintenance of savanna vegetation structure (Scholes and Walker, 1993; Riginos and Grace, 2008). The KNP elephant population was established to be approximately 12 430 individuals at a density of 0.63/km^2, at the time of my study (Blanc *et al.*, 2007). The private reserves had a combined abundance of approximately 2829 individuals at a density of 0.98/km^2, at the same period (Blanc *et al.*, 2007).

DATA SOURCES:

Elephant location data

Elephant location data were obtained from the "Save The Elephants" Organization (www.savetheelephants.org). The elephants had been fitted with GPS collars (Africa Wildlife Tracking cc) which download via a global system for mobile communications (GSM) network (using Hawk by YRless). These collars provide location data that are accurate to within approximately 10 m (Henley and Henley, 2007). Location data for collars were collected every five hours. I converted hourly data to five hourly intervals in order to standardize between individuals and time periods. Elephant location data between November 2005 and October 2007 were analyzed. Each of the 15 elephants was treated as a sample unit.

Satellite Imagery:

I used MODIS (version 5) NDVI imagery as a measure of the vegetation greenness. NDVI values are reduced by cloud contamination, sun angle and shadow effects. Consequently, I used the 16-day maximum value composite to reduce noise (Holben, 1986; Reed, *et al.*, 1994; Huete *et al.*, 2002; Chen *et al*, 2004). The NDVI data was at a 250 m resolution.

I used elevation (DEM) at a 90 m resolution (www.srtm.csi.cgiar.org), as a covariate to see if it could assist in explaining the trends observed with NDVI. Specifically, it is possible that specific vegetation types are associated with particular elevation (Cole, 1986; Scholes and Walker, 1993).

EXPERIMENTAL DESIGN AND ANALYSES:

My study analyzed data between November 2005 and October 2007, and included two wet and two dry seasons. These seasons were defined from the mean monthly rainfall data of seven weather stations near the elephant ranges (Ingwelala, Kingfisherspruit, Talamati, Letaba Mahlangeni, Phalaborwa, Shimuwini and Letaba - www.weathersa.co.za). From this, the dry season was defined as April-October and wet season as November-March. These were converted to 7 April-31 October and 1

November-6 April to correspond with the dates of the NDVI composites. Six elephants had data for both years.

Sixteen day scale: The 16-day period was the finest temporal resolution available for analyses. There was a total of 23 16-day periods per year, 10 in the wet season and 13 in the dry season. Elephant locations within each 16-day period were defined as used locations. A 95% adaptive kernel with least square cross validation was created for these locations using the home range tool for ArcGIS (http://blue.lakeheadu.ca/hre). The kernel is a home range measure that estimates the statistical utilization distribution and can exclude areas used for excursive activity (Worton, 1989; Blundell *et al.*, 2001). The kernel method is considered better than the common alternative minimum convex polygon method because the kernel provides better estimations of used areas, and it is robust to outlying points (Katajisto and Moilanen, 2006). Within the kernel 16-day home range, random points were created at a ratio of 1 used: 10 random points (Fig. 2A). Values from NDVI and DEM were extracted for the used and random available points. The same procedure was followed for all 16-day periods. At this scale, comparison was between these used and available points.

Seasonal scale: The next scale of analysis considered the seasonal distribution (95% adaptive kernel using all observations per elephant for each season) as the available area and the 16-day home range as the used area (Fig. 2B). The comparison at this scale was between the used 16-day home range and the 10 random available home ranges for all 16-day periods in each season. For each 16-day period, 10 circular home ranges of area equal to the observed 16-day home range were created and randomly distributed within the seasonal home range to estimate the available area (Fig. 2C) (Katnik and

Wielgus, 2005). At this scale the analysis was done on the mean values of DEM and NDVI within the home ranges.

STATISTICAL ANALYSES:

I used the logistic regression model to look for an association between greenness and the choice of used verse random available resources (Manly *et al.*, 1993) for each scale and season. A difference between used and random available locations at $p < 0.10$ was judged as evidence of an association with the independent variable (NDVI or DEM). Separate analyses were done for each elephant. Statistics were done in SAS 3.0 (www.sas.com) and spatial analyses were done in ArcGIS 9.2 (www.esri.com) with all data being projected to the georeference WGS-1984.

RESULTS:

Analysis included data from 15 elephants (11 males and four females). All of the females were adults and the males were divided into two sub-adults, three adults and six senior adults. There were a total of 26930 locations with a mean of 1795 per elephant ± 410 (standard deviation).

SIXTEEN-DAY SCALE:

Contrary to my first hypothesis, more elephants had evidence of an association with NDVI at the 16-day scale day scale than at the seasonal scale (Fig. 3). Also contrary to the initial predictions more elephants were associated with lower NDVI than was randomly available, 3 of 4 and 2 of 3 individuals for wet and dry seasons respectively

(Fig. 3). Evidence of an effect of DEM was also apparent for more elephants at the 16-day scale than at the seasonal scale (Fig. 4). The digital elevation model explained more of the variability in elephant data then did NDVI, with more elephants having evidence of an association with higher elevations than lower elevations (Fig. 4).

SEASONAL SCALE:

No elephants showed evidence of an association with NDVI at the seasonal scale (Fig. 3). Therefore the prediction of the second hypothesis of increased association during the wet season was not supported. Two elephants in each season showed evidence of an association with DEM (Fig. 4). In the wet season, one elephant showed evidence of an association with higher and one with lower used elevations. In the dry season, two elephants showed evidence of an association with higher elevations.

COMPARISON BETWEEN SEXES AND SEASONS:

At the 16-day scale, all four females had evidence of an association with NDVI in the wet season, but none showed evidence of an association in the dry season (Fig. 5). No males showed evidence of an association in the wet season, and three of eleven males had evidence of an association with NDVI in the dry season (Fig. 5).

The trend of increased evidence of association with NDVI by males in the dry season (Fig. 5); was also evident in the DEM data (Fig. 6). The number of individuals with evidence of an association with DEM between the wet and dry season remained the same for females and sub-adult males (Fig. 6). However, while three of the nine adult and senior adult males showed evidence of an association with DEM in the wet season, six showed evidence of an association in the dry season (Fig. 6).

DISCUSSION:

Contrary to my first hypothesis, more elephants were selective at the 16-day scale than at the seasonal scale. No elephants showed evidence of an association with NDVI at the seasonal scale. As a consequence, there is no support for my second hypothesis that there are seasonal differences in the association with NDVI at this scale. Elephants that showed evidence of an association at the 16-day scale, tended to be associated with lower NDVI values. This is also contrary to my initial prediction, as elephants were expected to be associated with higher vegetation quality or quantity (i.e., higher NDVI values). The pattern of higher numbers of elephants showing evidence of selection at the 16-day scale than at the seasonal scale was also found for DEM. The digital elevation model explained more of the variability in elephant locations data than NDVI. Elephants were expected to use lower lying areas during the dry season (Shannon *et al.*, 2006); however, most elephants were associated with higher elevations during both seasons. It is suspected that this pattern between elephant location and DEM was a result of selection for another resource. When differences between sexes and seasons were compared, more males had evidence of an influence of NDVI and DEM during the dry season than in the wet season. This is in accordance with a previous study (Stokke and du Toit, 2002).

The pattern of larger numbers of elephants showing evidence of selection at the 16-day scale than at the seasonal scale was found for both NDVI and DEM. It might be expected that larger animals would demonstrate selection at larger scales (Boyce, 2006);

however, this would be relative to other herbivores. Habitat selection for foraging processes, however, generally occurs at finer scales than population processes (Boyce, 2006). I can not conclusively determine the scale at which elephants select for their environment because the results are subject to the methods employed.

The methods used could have resulted in the pattern of more evidence of associations at the smaller scale than the large. The comparison, was between used and available points at the 16-day scale, while at the seasonal scale, it was between the mean values for observed and random home range areas. As a result, the sample size at the seasonal scale was much lower than that at the 16-day scale, which could have contributed to the lack of evidence of an association with both DEM and NDVI at the seasonal scale. An important consideration with regards to the sample design is that when comparing used-available, the used and “available” areas could overlap (Keating and Cherry, 2004) which will lower the probability of finding evidence of an association. Therefore, with the used-available method utilized, there is an assumption that the probability of use in areas defined as “available” is minimal (Keating and Cherry, 2004). The available area at the seasonal scale was defined by 10 randomly placed home ranges within the seasonal home range, each equal to the area of the used home range. Thus, there is an assumption that the available area is at least ten times larger than the used 16-day home range. However, there will be spatial overlap between consecutive 16-day home ranges resulting in the seasonal home range not being as large as assumed. Also the elephants could cover a larger area of their seasonal home ranges within a 16-day period, depending on the area of the seasonal home range and the individual’s movement behaviour during that period. While possibly unavoidable at the 16-day scale, the association with NDVI and DEM might have been more evident had know used areas been excluded from the area defined as available for the seasonal scale comparison.

The finding that no elephants showed evidence of an association with NDVI at the seasonal scale was not restricted to that scale as most showed no evidence of an association at the 16-day scale as well. This suggests that NDVI is not a good predictor of elephant locations based on the individuals monitored and the methods applied in analyzing associations and the 250 m resolution might be inappropriate. Alternatively, it could be due to the generalist foraging patters of elephants (Laursen and Bekoff, 1978; Cordon *et al.*, 2006) which reduces the likelihood of finding associations.

The data used could have contributed to this lack of evidence of an association with NDVI. This overall lack of evidence of an association with NDVI along with the greater evidence of associations at the 16-day scale could indicate that elephant habitat selection occurs at smaller scales than those represented by our imagery (Boyce, 2006). Furthermore, it is possible that the more numerous evidence of selection for the DEM data (90 m) was because it was closer to a biologically relevant scale for elephants than the NDVI data (250 m). However, NDVI is spatially and temporally variable; but, DEM is spatially variable but constant over time. As a result, the capability of elephants to track greenness and the consequent probability of finding an association with NDVI is reduced compared to DEM. Additionally some studies have restricted observations of elephant locations to daylight hours (Stokke and du Toit, 2002). The data used in my study includes representation of every hour of the day and it is possible that foraging associations could have been more evident had sampling of elephant locations been restricted to periods when foraging occurs.

The lack of evidence of an association with NDVI would not necessarily contradict previous studies that considered elephant locations and NDVI. The relationship found by Muriwa and Skidmore (2005) was largely from the comparison between agricultural land and savanna vegetation. In contrast, my study was looking for finer-scale selection within the savanna vegetation type. Smit *et al.* (2007) found that there were differences in selection for NDVI between sexes during the dry season, which was also found in my study. While Chamaillé-Jammes *et al.* (2007) found increased elephant numbers in areas with increased NDVI, their analysis was done with the average yearly NDVI, limiting comparability with the current study. Also both Chamaillé-Jammes *et al.* (2007) and Smit *et al.* (2007) were focusing primarily at the effect of surface water availability on elephant distribution and not on that of NDVI.

Of the individuals with evidence of an association with NDVI, more were associated with lower NDVI values. These lower NDVI values should represent a particular structure or composition of vegetation; possibly indicating use of lower vegetation quality or quantity. The foraging maturation hypothesis proposes that there is a tradeoff, between selection of new leaves at low biomass and mature leaves which are high biomass but low quality, resulting in an intermediate biomass being favoured (Hebblewhite *et al.*, 2008). Thus in the disturbance-driven system of savannas (Scholes and Archer, 1997), elephants may avoid undisturbed (higher biomass with mature foliage) in favour of disturbed areas (lower biomass- but with quality regrowth) possibly explaining the evidence of associations with lower NDVI. Males in the KNP can occur in open grassy plains during the dry season (Smit *et al.*, 2007), which could explain the lower NDVI used by some males during the dry season as the grass would be senescent and have a low NDVI value at this time. There are spatial and temporal differences in the proportion of grass and browse consumed by elephants (Cordon *et al.*, 2006). Different greenness values might represent different tree-grass ratios; however, a limitation of using NDVI alone, is that if these differences exist, they cannot be interpreted without the use of vegetation cover maps. Hence selection for a particular tree-grass ratio might be indicated by a lower NDVI value compared to alternative available tree-grass ratios; however, this can not be interpreted. Another limitation of NDVI is that several plant species can have similar reflectance (Pettorelli *et al.*, 2005); thus, selection or avoidance of specific forage plants can not be interpreted. Avoidance of an abundant unpalatable species could also result in evidence of an influence by lower NDVI.

These associations with lower NDVI could be as a result of the images used. A limitation of the maximum value composite is that the entire period can be biased by a single false high value; however, the occurrences of such errors are not common (Pettorelli *et al.*, 2005). Such false high values in available areas could result in patterns of lower used NDVI. There might also be “the mixed pixel effect”, where a pixel contains for example both terrestrial cover and water resulting in an average NDVI value proportional to the amount of each cover type (Pettorelli *et al.*, 2005). Elephant locations near to water or bare patches result in lower NDVI values. In the current study, the mixed pixel effect is unlikely to be from locations too close to water as the elephants mostly showed evidence of selection for higher elevations.

The digital elevation model explained more of the variability in elephant locations data than the NDVI, with evidence of associations with higher elevations. The energetic costs of transversing hilly landscapes are higher for elephants than for lighter herbivores due to their weight (Wall *et al.*, 2006); consequently, it is expected that there is some benefit to using high elevations. One possibility is a thermoregulatory benefit of being at cooler elevations. Another explanation could be that because elephants select for heterogeneity of the environment (Grainger *et al.*, 2005; Murwira and Skidmore, 2005), the greater aspect diversity at higher elevations (Hebblewhite *et al.*, 2008) contributes to this pattern. Also increased altitudinal heterogeneity will result in an increased surface area within that pixel which might also affect the NDVI values and animal distributions. This effect has not been documented as yet and it may be useful for research to ascertain such effects.

The relationship with DEM could be an effect of an association with a particular vegetation type or plant species which is associated with higher elevations. For example, Acacia-Marula woodlands are selected for by elephants in the wet season (Shannon *et al.*, 2006). Marula trees (*Sclerocarya birrea*), are associated with sandy soils on hills or low ground with underlying syenite (Cole, 1986). It is browsed on by elephants, and they make use of its nutritious fruits (Morris *et al.*, 2006). Some elephants change their seasonal movements in response to fruiting seasons of other plant species (White, 1994). If selection by elephants was only a response to fruit, it would be expected to have a strong seasonality. However the association with higher used locations occurs in both seasons showing that the influence of fruit would not be the only explanation. Also fine-leaved plants at lower elevations tend to have mechanical defenses while broad-leaved plants usually found at higher elevations, have chemical defenses (Scholes and Walker, 1993). It is possible that elephants are adapted to consume the broadleaved vegetation at higher elevation as their large bite sizes makes avoiding thorns and spines more difficult (Scholes and Walker, 1993).

Distance to water was proposed as another covariate in addition to DEM. However quality water distribution data were not available for inclusion in my study. While the importance of water to animal distributions is acknowledged it is presumed to have less of an effect due to the abundance of available water in my study area (Parker and Witkowski, 1999; Grainger *et al.*, 2005). Furthermore vegetation greenness and low elevation should be correlated with water availability.

The selection patters displayed by males during the dry season confirms a study by Stokke and du Toit (2002). They found that males use a larger range of habitats and are more selective than family herds during the dry season, and this trend is reversed in the wet season. This sex-specific habitat selection could be a result of intra-sexual avoidance of conflict with males in musth (associated with the females) rather than inter-sexual competition (Stokke and du Toit, 2002).

Males range further away from water in the dry season than females (Stokke and du Toit, 2002; Smit *et al.,* 2007), and this might explain the more frequent evidence of association with higher elevations in the dry season, as they travel away from rivers at low elevation. However, it does not explain the use of higher areas by females. There is a shift to a higher proportion of grass in elephant diets during the wet season (Cordon *et al*., 2006), and this change could result in the change in selection of greenness between seasons.

Elephants have complex social interactions (Couzin, 2006; Smit *et al.,* 2007) implying that the male and female distinction is not sufficient to explain the behavioural influences on elephant location. For example, the distribution of some males might overlap with that of females whilst others do not. These social interactions were not analyzed, which limits inferences that can be drawn about sexual differences.

Elephants consume larger quantities of food as they age (Laws *et al.*, 1975). A larger proportion of older males had evidence of an association with NDVI than sub-adults; however, it is difficult to make conclusions on the quantity of food consumed from these results.

It is important to note that when there was evidence of associations with NDVI and DEM all individuals were not selecting for the resource in the same direction. The different directions of selection for NDVI and DEM between individuals might be a consequence of different habitat selection by different individuals, which are under different conditions (Grainger *et al.*, 2005). This is important for future studies, as habitat selection studies observing few individuals could result in misleading results, distorting interpretation.

CONCLUSION:

NDVI is not a good predictor of elephant locations based on the 15 elephants studied and the methods used. It is suggested that further research takes place into understanding how tree-grass ratios influence NDVI values. Interestingly, many elephants were associated with higher elevations. A number of mechanisms were proposed and further studies should test these and investigate alternative causes of this phenomenon. In accordance with the findings of Stokke and du Toit, (2002); males were found to be more selective for both NDVI and DEM during the dry season. My study is useful; because, understanding how animals react to their environment will be crucial for predicting the impacts of climate change (Pettorelli *et al.*, 2005).

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Table1: Comparison between 9 reviewed elephant habitat selection studies.

Paper	Between sexes	Between Seasons	Sampling periods	#Scales and comparison	Data	Study Period (yrs)	Study area
Babaasa, 2000	N	Y	8 days a month for 9 months	1-Vegetation type	Elephant tracks	0.75	Uganda Bwindi Impenetrable Nature Reserve
Stokke and du Toit 2002	Y	Y	Discontinuous	1-Vegetation type	Field observations	2	Botswana Chobe
Grainger *et al.*, 2005	Y	Y	Unknown	1- landscape heterogeneity	Radio-telemetry	16	RSA, KNP
Muriwa and Skidmore, 2005	N	N	Discontinuous- 2 periods 10 years apart	1- Some consideration of scale - vegetation heterogeneity	Population distribution (3yrs per period census data) NDVI	snapshots (2) that are 10 years apart	Zimbabwe Sebungwe
Corden *et al.*, 2006	N	Y	Unknown- seemingly Discontinuous	1-Vegetation type	Carbon isotope of feces	2	RSA, KNP
Shannon *et al.*, 2006	Y	Y	Discontinuous 6-10am 3times a week	1-Vegetation type	Field based GPS locations	2	RSA Pongola Game Reserve
Chamaillé-Jammes *et al.*, 2007	N	N	Discontinuous- yearly census data	1-NDVI, water availability	Census data	20- but yearly comparison	Zimbabwe Hwange National Park
Smit *et al.*, 2007	Y	N	Discontinuous- Census data collection only in dry seasons	1- NDVI, tree cover and distance to water	Census data	12yrs. But combined to one distribution	RSA, KNP
Harris, *et al.*, 2008	Y	Y	Variable- locations taken every third day	1- vegetation type, water and human settlements	GPS locations	2	Southern Africa- 3 parks

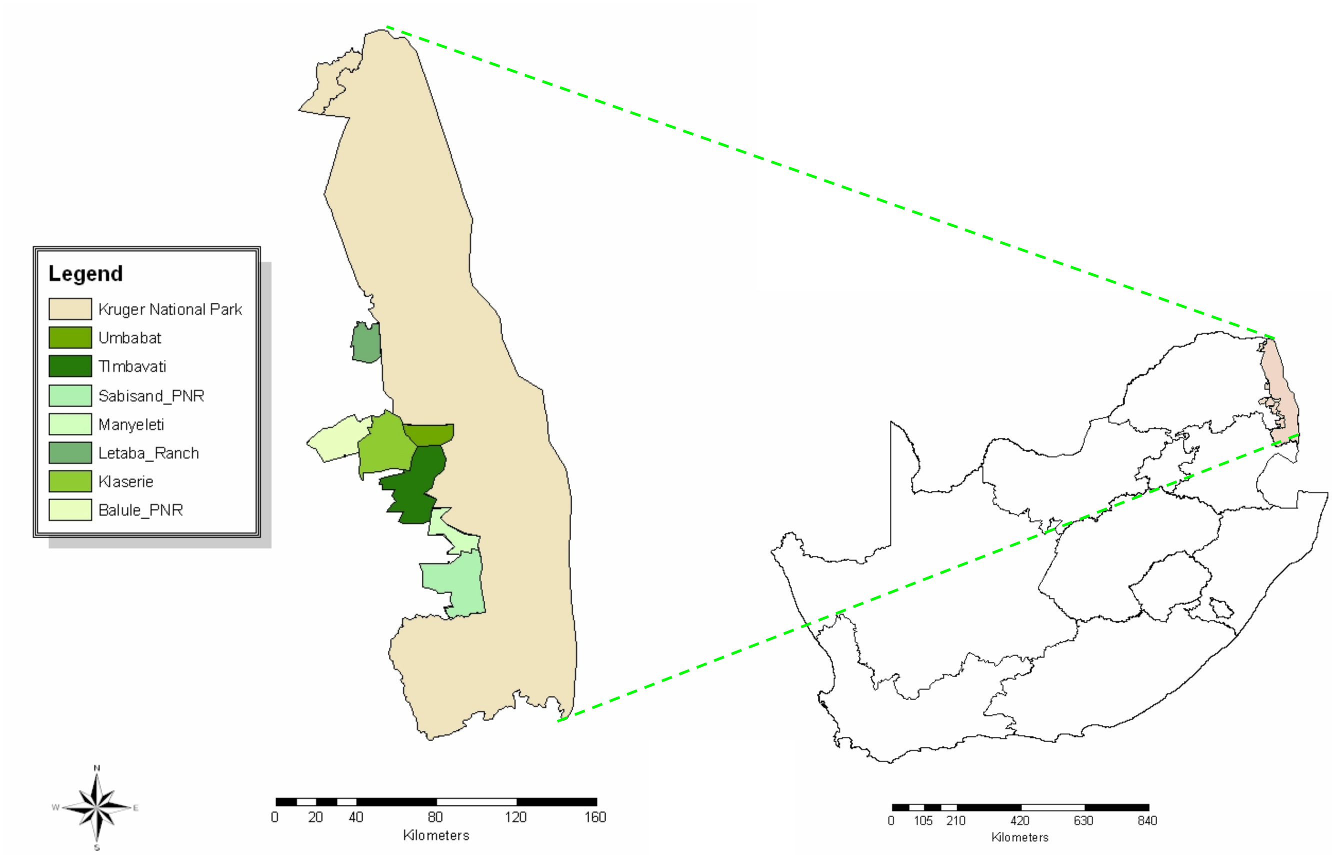

Figure 1: Map showing the position of the reserves where the study elephants were located relative to South Africa (right). The large area is the Kruger National Park and the regions to the west are the private reserves.

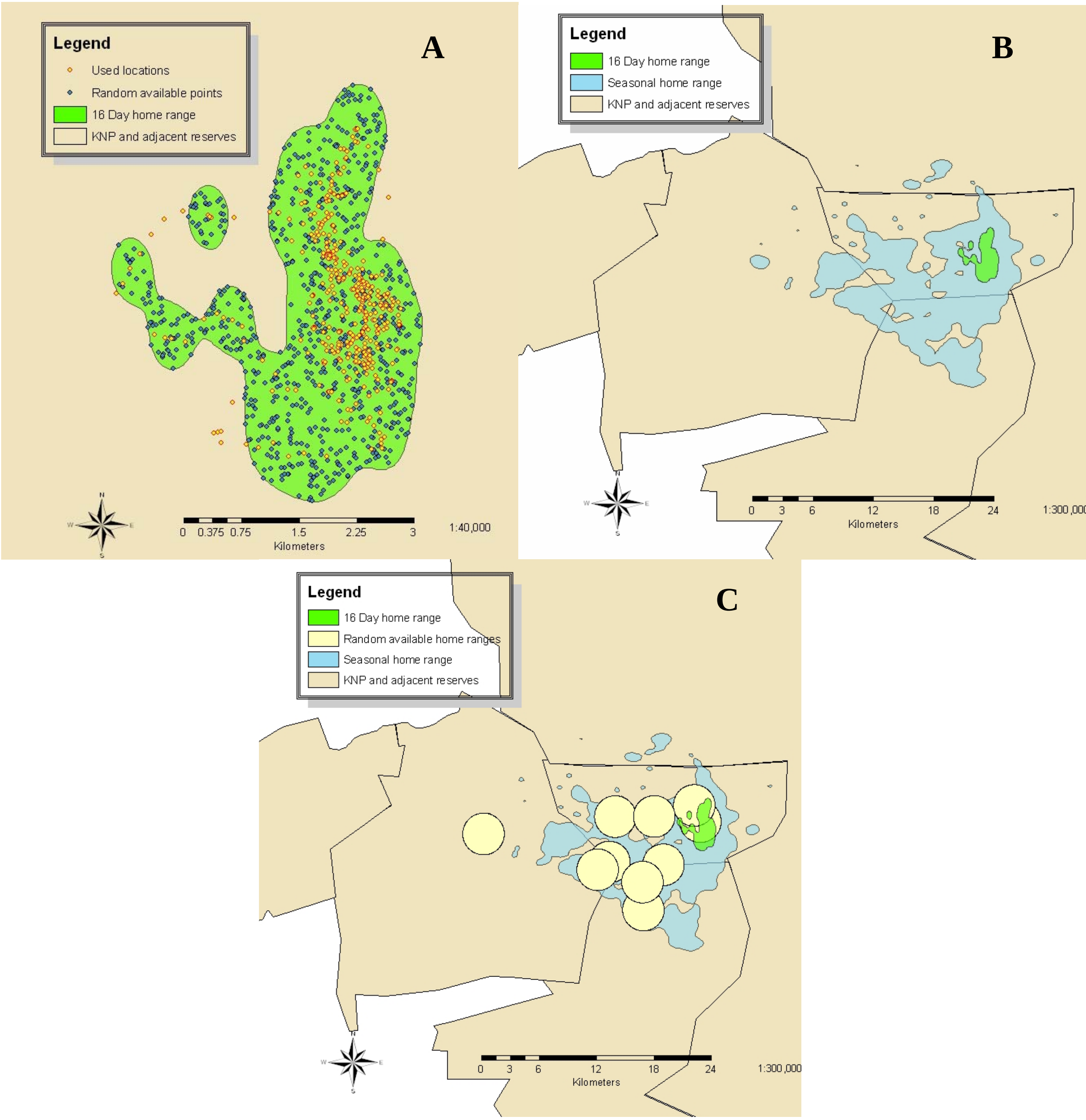

Figure 2: Diagram representing the spatial scales that will be considered for the relationship between greenness and elephant locations. A- Illustration of the comparison at the 16-day scale between used (yellow with red outline) and random available points (Blue), B- The areas defined as available at the 16-day and seasonal scales, C- Illustration of the comparison at the seasonal scale between used (Green) and random available home ranges (Beige).

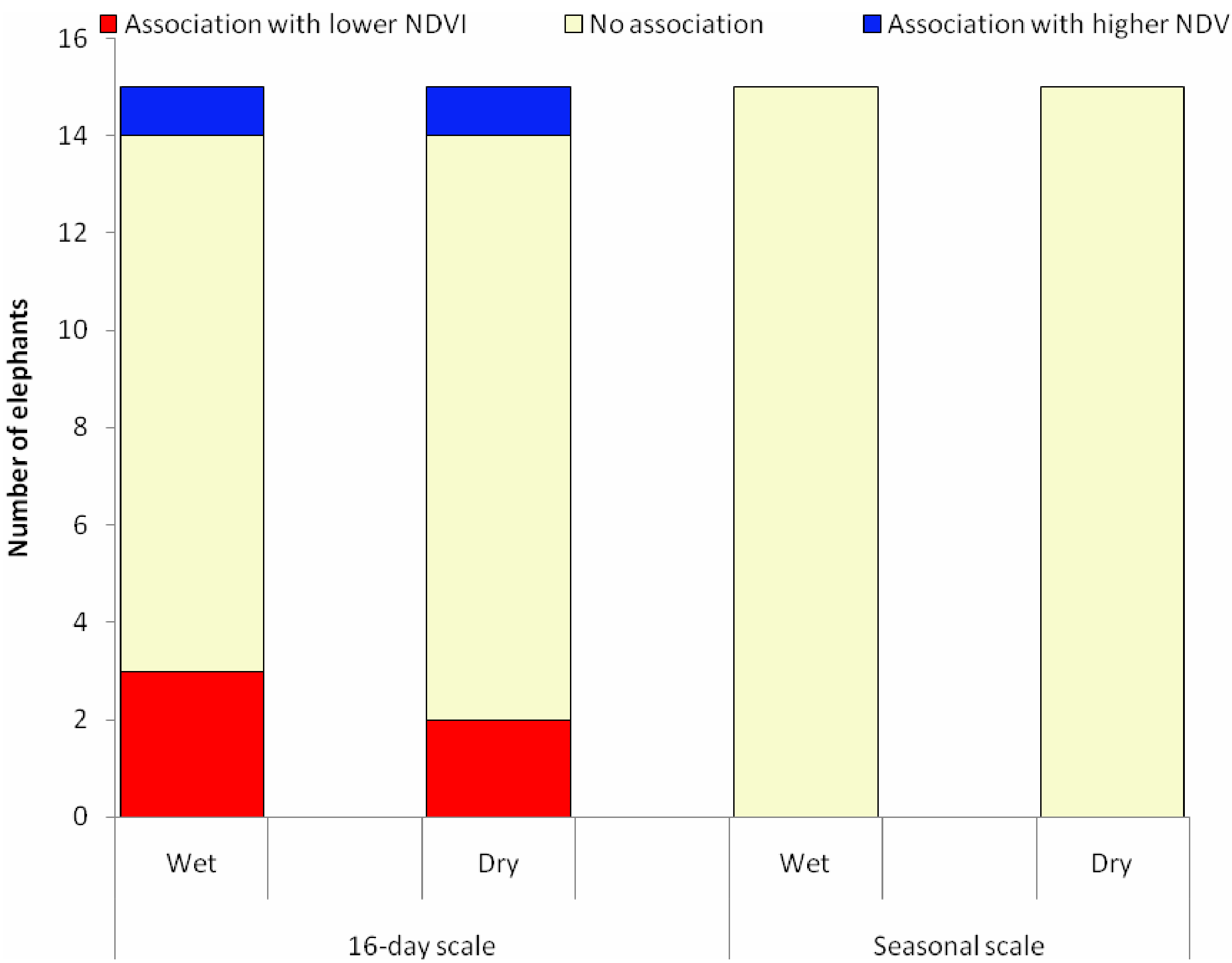

Figure 3: The number of elephants associated with NDVI, separated by season and scale

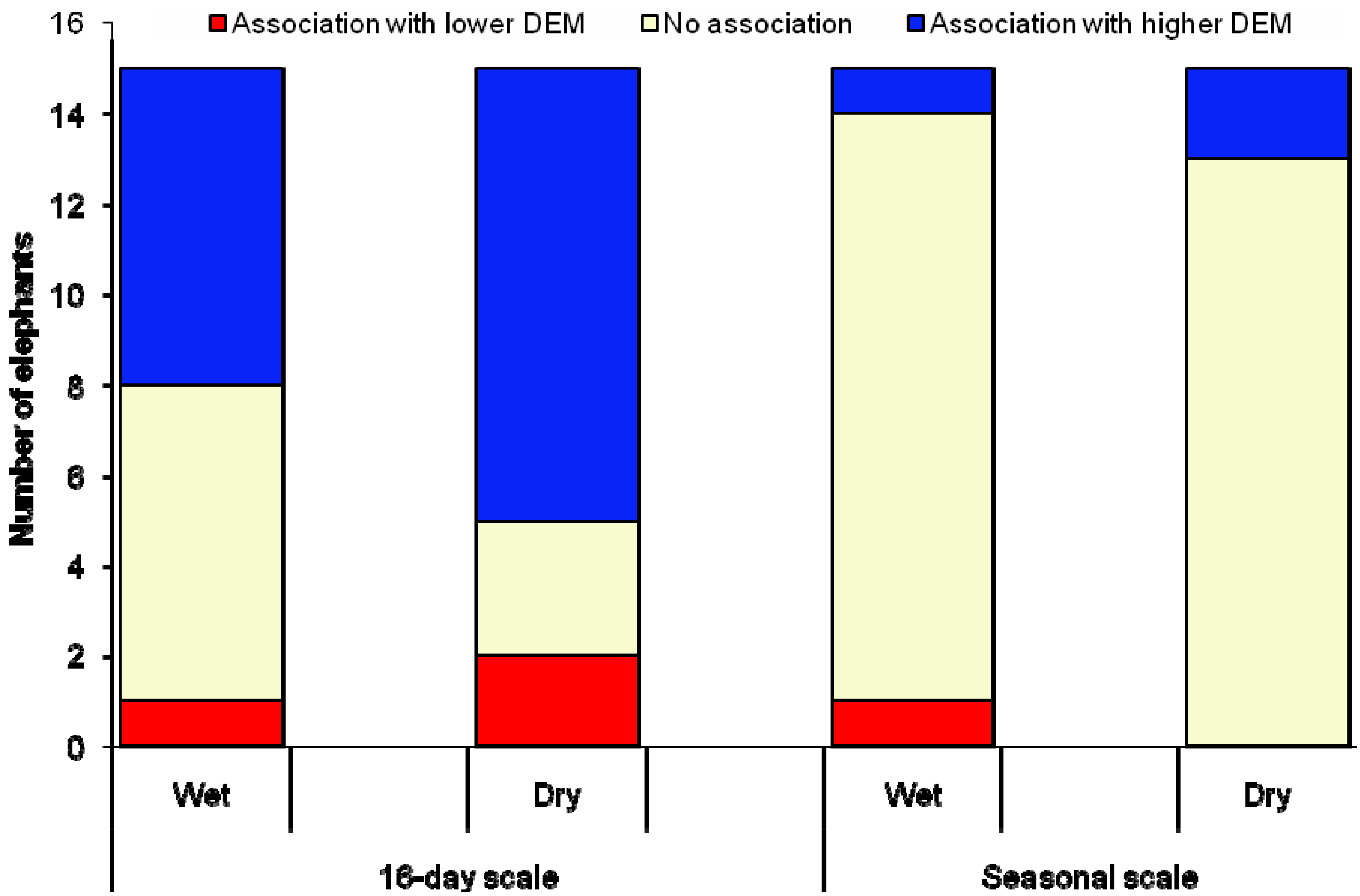

Figure 4: The number of elephants associated with elevation, separated by season and scale

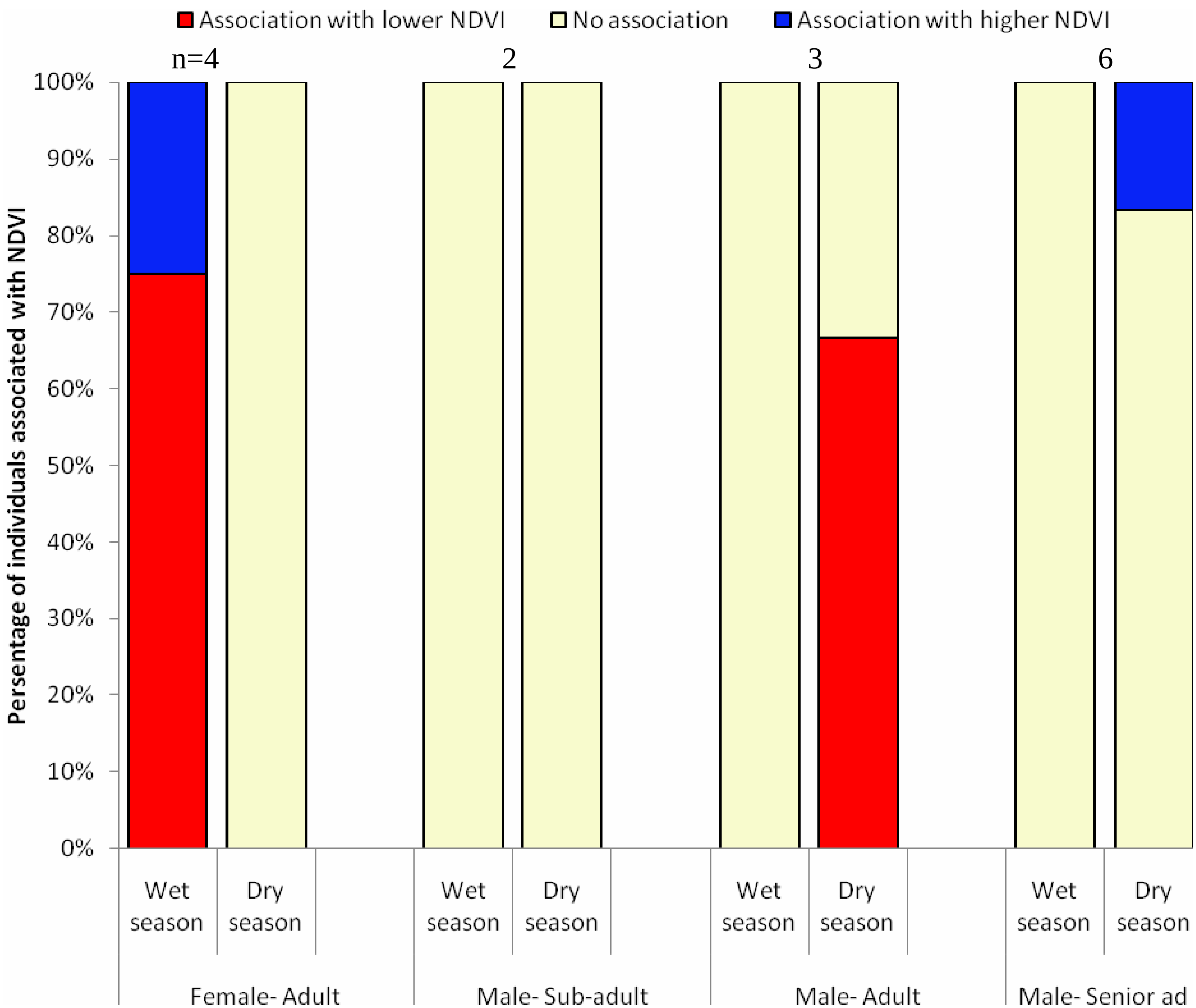

Figure 5: Percentage of individuals with evidence of an association with NDVI at the 16-day scale. Data seperated by sex and age class. Numbers on top of bars represent sample size of that group.

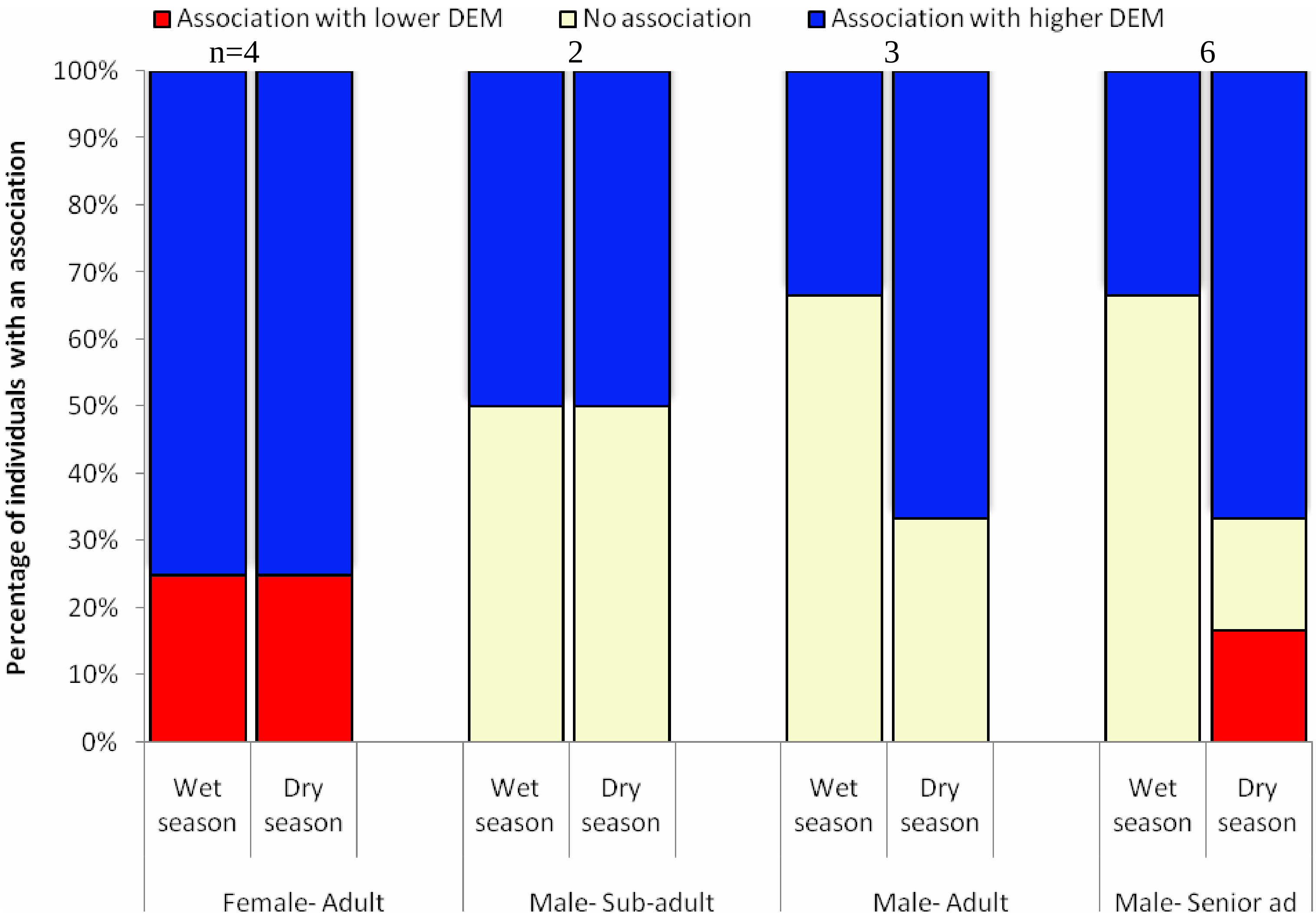

Figure 6: Percentage of individuals with evidence of an association with elevation at the 16-day scale. Data seperated by sex and age class. Numbers on top of bars represent the sample size of that group.