Research Article

Plant biomass density as an indicator of food supply for elephants (*Loxodonta africana*) in Waza National Park, Cameroon

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Abstract

We studied the aboveground biomass density of plants, potentially available as a food supply for elephants, *Loxodonta africana*, in the Waza National Park, Cameroon during the dry season, from November 2009 through March 2010. The aboveground biomass of trees in the Woodland and *Acacia seyal* shrubland zones, were 16.87 tonsDM/ha and 10.99 tonsDM/ha respectively (mean 13.93 ± 4.16 tonsDM/ha). Aboveground biomass density in the herbaceous layer was 2.62, 4.21 and 6.9 tonsDM/ha, in the Woodland, *Acacia seyal* shrubland and Floodplain zones, respectively (mean 4.58 ± 2.16 tonsDM/ha), the difference between the vegetation zones being significant. The overall aboveground plant biomass density of the park averaged 13.86 ± 6.4 tonsDM/ha, however the harvestable food supply for elephants was a small portion of that estimate. The estimated plant biomass represented an average for the dry season, which is more useful for long-term planning purposes than for annual predictions of the level of forage production in the dry season. To minimize elephant encroachment into cultivated fields, it is necessary to estimate the park's carrying capacity and regulate the population size if necessary. This however will rely on the long-term prediction of forage production in the Waza National Park through continuous measurements of plant biomass density during the dry season.

Keywords: Carrying capacity, Cameroon, elephants, food, plant biomass, Waza National Park

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Introduction

The Waza National Park (WNP) was set aside for the conservation of wildlife biodiversity, including the elephant (*Loxodonta africana*) population with an estimated size of 496 in 2010 [1]. This represents a decrease of 77.5% compared to a 1995 estimate of 1100 [2], indicating that the Waza elephants are facing serious threats, specifically from poaching for ivory. Despite such a decrease in population number, in the last decade there have been recorded break-out movements of elephants, mainly in November (the beginning of the dry season), which resulted in an increase of human-elephant conflicts in areas around the park [3], for reasons that remain to be explained. It was recently hypothesized that scarcity of food and water for the elephant population within the WNP could be the cause [4]. However, no relationship between the availability and quantity of forage and elephant abundance has been found. This leaves a void in the understanding of the interactions between elephants and their environment, and a setback for meaningful management programs. Assessing the total aboveground plant biomass, which is biomass density expressed as dry weight per unit area [5], appeared to be a useful means of quantifying the amount of food resources available for elephants and other herbivores in the park during this critical period.

Plant biomass density is relevant to issues of animal foraging in the natural environment. For instance, the spatial distribution of foraging animals is strongly influenced by food availability [6]. Additionally, food resources change predictably, in quantity and quality, with the seasons, concurrently with changes in herbivore behaviour [7]. At the extreme, herbivores migrate long distances between seasonal feeding areas; Wildebeest and Caribou are among the best-known seasonal migrants [8, 9]. The importance of food supply for migratory populations has been emphasized by ecological studies on ungulates [10, 11]. In some conservation areas, limited supplies of food may regulate herbivore populations [12]. Large herbivores utilize their environment according to what plants are available in space and time, or by adapting to their social organization [13].

Patterns of wild plant species use by elephants in the WNP revealed that out of 45 plant species recorded, elephants selectively foraged on 20 [14]. The low number of plant species consumed by the elephants is due to their dependence on cultivated crops, which have higher palatability and nutritive value than wild plants. It has been postulated that ungulates show a positive selection for plant species and plant parts that have the highest protein value [15]. The efficiency of digestion depends on a combination of the passage rate of food through the digestive track and the rate of nutrient extraction [16], however the relationship between those two factors become more influential of foraging patterns in species which base their foraging strategy on maximizing digestibility, rate of digestion, and energy. The relationship between passage rate and rate of nutrient extraction may be important determinants of how well elephants can use a particular food source, and has been found to influence food choice in several groups of herbivores [17]. The selective feeding behaviour of elephants changes according to the season, and is dependent on the nutritional requirements and food availability during that particular period [18].

Plant biomass densities are extremely relevant for studying the ecological carrying capacity of elephants' natural habitat, as the daily food consumption of ungulates is estimated at 7.1% of their metabolic body weight $W^{0.75}$ [13], where W is the population's mean body weight. Pfeffer [19] suggests that an elephant can consume 100-200 kg of forage daily, depending on its size and the vegetation type available. These features make it possible to determine, for a given period, the number of elephants/day that a given pasture can support.

Although extensive ecological studies have been carried out on elephants in WNP and its surroundings [4], studies of food supply for foraging elephants are lacking. In particular, there is very little research on the strategies that animals adopt to cope with a shortage of forage in the ecologically and economically important WNP. The WNP represents a critical area of biodiversity and high productivity in an otherwise dry area, where rainfall is uncertain and livelihoods are extremely insecure [20]. Just under 220,000 people are estimated to live in the Waza Logone region, including the WNP, approximately 60% of whom (or 85% of the rural population) rely on floodplain and wetland resources (plant and animal) for their basic income and subsistence. Savannahs are highly seasonal environments subject to fluctuations in the types and amounts of food that are available [13]. To determine whether food is the limiting factor for elephants, ecologists have searched for correlations between abundance, distribution, movement, and productivity of individuals and food supply [21, 22]. Others have tested the hypothesis that the number of animals is regulated by food in a density-dependent manner [23]. In order to determine whether the dry season migration of elephants outside WNP is due to a lack of sufficient forage inside the park, we assessed the food supply potentially available to the elephants within the WNP during the dry season, by estimating the biomass of available potential food plants. In this study, we used trees/shrubs and standing herbaceous plant crops as indicators of food supply.

Methods

Study area

The WNP is located in the Waza Logone floodplain, which comprises about 10% of the total surface area of major riverine wetlands in the West African Sahelian zone. The WNP is near Lake Chad in Northern Cameroon and lies between 11°00’ - 11°30’ N and 14°30’- 14°75’ E (Fig. 1). It covers an area of approximately 170,000 ha with an average altitude of 300 - 320 m. The park lies in the Chad depression in an area of low relief with no permanent rivers. Soils are mainly ferruginous tropical with various catenas, hydromorphic soils, and vertisols. The climate of the region is semi-arid, with a dry season extending from October to May. Rainfall is irregular, with an annual mean rainfall of 700 mm. The mean annual temperature is 28°C. Water continues to be one of the most serious problems for WNP.

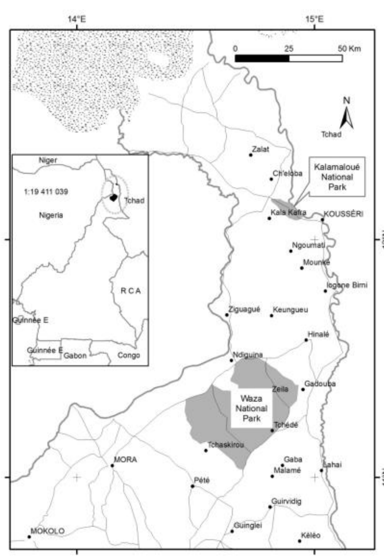

Fig 1. The Waza-logone region displaying the study area. The inset on the left is Cameroon

The park includes three main vegetation types. The woodland zone covers approximately 31 % of the park, and consists mainly of marula (*Sclerocarya birrea*), *Lannea humilis* and African birth (*Anogeissus leiocarpus*). The shrub savanna covers about 27 % of the park and is dominated by the whistling thorn (*Acacia seyal*). The floodplain grassland, locally known as "yaérés," consists of perennial grasses such as the vetiver grass (*Vetiveria nigritana*) that are being replaced by annuals like the wild sorghum (*Sorghum arundinaceum*), chocolate weed (*Melocia corchoriflora*) and common cockscomb (*Celosia argentea*). It covers approximately 42 % of the park. The WNP is one of the best known parks of central and West Africa due to its diverse wildlife. Its diverse wildlife includes elephants, giraffes (*Giraffa camelopardalis*), lions (*Panthera leo*), ostriches (*Struthio camelus*), various species of antelopes and Palearctic migratory birds.

Habitat sampling

Sampling was conducted in the dry season from November 2009 to March 2010. An initial reconnaissance survey was conducted of different vegetation types, to select suitable sites for laying sampling quadrats. Plant standing biomass available for animals was then assessed using Floret [24] recommendations. Specifically, a non-destructive method was chosen to measure tree biomass, while herbaceous species were harvested, oven dried and then weighed. Sampling sites were selected to represent the "average" vegetation of the area, taking into account the environmental conditions and vegetation homogeneity. Sample units were defined as 900m^2 quadrats for woody species and 1m^2 quadrats for herbaceous species.

A total of 34 woody species quadrats with an area of 900 m² each (or 30 x 30 m) were selected, unequally distributed over the entire study area proportional to the size of each vegetation zoneb land zone, and 20 quadrats, regularly spaced 500 m apart along a 10 km line transect, in the floodplain (grassland) zone (Fig. 2). In selecting the sampling quadrats, we chose those areas that were most representative of the overall vegetation in the park and areas known to be intensively used by elephants. For each quadrat, data on the plant species, structure, and biomass were collected once. All species of tree, shrubs and grasses were identified immediately in the field. All data in each quadrat were recorded on data sheets prepared for this purpose.

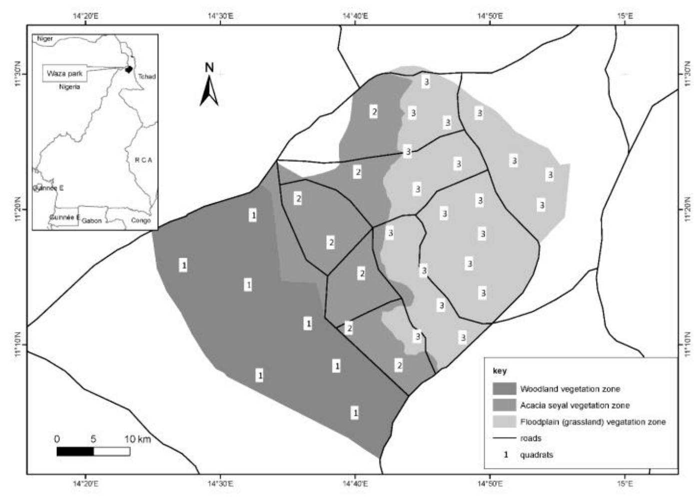

Fig 2. Major vegetation zones of the Waza National Park and approximate locations of the sampling quadrats per vegetation zone. The inset on the left is Cameroon.

The number of herbaceous quadrats within a vegetation zone, was dependant on the floristic composition of the herbaceous layer, being higher if more the layer was more heterogeneous. A total of 74 herbaceous species quadrats with a $1m^2$ area (10 x 10 cm) were chosen; 15 were chosen in the woodland zone, 17 in the *Acacia seyal* zone, and 42 in the floodplain zone. The location of each quadrat was obtained using a Geographical Positioning System. For each sampled quadrat, a complete list of plants species present was compiled. It was not always possible to identify individual species because some annual grasses had already completed their life cycle.

Above-ground biomass of herbaceous species

In each $1m^2$ sampling quadrat, all herbaceous species were clipped at 1cm above ground and weighed with a dynamometer to determine fresh matter weight. Later each sample was taken in a cloth bag to the laboratory and oven dried at 80°C for 24 hours, then weighed again to determine dry-weight. The mean value of the dry matter obtained within quadrats was converted into biomass expressed in tons of dry matter per hectare.

Above-ground biomass of shrubs/trees.

Methods used to estimate tree productivity are undeveloped, and detailed works have been restricted to relatively few sites [25]. One problem has been that different standards of measurement have been applied in different situations. In some cases, only the edible or accessible portions of the vegetation have been measured, while in others, total biomass production was determined. The plant parts that are accessible or usable by animals vary among species and environments, and there is considerable variation in production within species, which makes it difficult to obtain reliable data without increasing sampling time and cost. Also, determining the fresh weight of an individual tree by weighing all tree components or by sampling may be difficult because for relatively large trees, weighing of the entire tree can be quite time consuming and laborious. To minimize fieldwork, sampling procedures such as the use of radioisotopes are often applied. Unfortunately, this method was not accessible to us due to its cost.

The most common method for determining total above ground biomass or productivity is through the use of allometric equations. These equations predict biomass of individual plants or their components from some easily measured variables such as diameter and height [26]. In this study, we chose the approach of Brown [5], which directly estimates biomass density using regression equations. These regression equations are mathematical functions that relate oven-dry biomass per tree as a function of a single or of multiple trees' dimension. They produce biomass estimates without having to make volume estimates, followed by the application of expansion factors to account for non-inventoried tree components [5]. Thus, within each sample unit, all trees' stem diameters at breast height (DBH) were measured. The basal area (BA) of individual stems was derived from the measure of stem diameter. The measurements of these indicator variables were related to actual recorded biomass.

Data compilation and analysis

Aboveground biomass of trees was calculated using the allometric equation adopted from Brown [5] applying the equation for dry zones with rainfall less than 900 mm/year, based on basal area and expressed as follows:

$$Y = 10^{\{-0.535+\log_{10}(BA)\}}$$

where Y is the aboveground biomass given in $kg.tree^{-1}$ and BA the basal area of tree in cm^2. Aboveground biomass of trees within each of the sampled quadrats, expressed as tons of biomass per hectare, was then calculated by computing the biomass of all the above plants. From these data (at the level of each sampled quadrat), average aboveground biomass (in tons per hectares) was calculated for each vegetation type of the park and over the entire study area. Aboveground biomass was compared between habitat types using one-way ANOVA.

Results

Distribution of trees across diameter classes

Juvenile individuals dominated the total structure of plants sampled, with the majority of trees having breast height diameters less than 20 cm within each vegetation type (Appendix 1). Large sized trees more than 25 cm in diameter at breast height are present in a scattered distribution, leading to low relative densities in one-hectare sampling units. Trees of this size were more abundant in the woodland zone than in the *Acacia seyal* zone (Appendix 1).

Plant biomass of trees in different vegetation units

Woody vegetation in WNP averaged 13.93±7.3 tonsDM/ha of plant biomass (Table 1), with no significant difference between the *Acacia seyal* and the woodland zones ($p<0.05$). There was a tendency for the woodland zone, on average, to have more tree biomass (16.87±6.52 tonsDM/ha) than the *Acacia seyal* zone (10.99±7.29 tonsDM/ha) (Appendix 2). The smallest plant biomass per unit area was found in quadrat number 6 of the *Acacia seyal* zone with 4.18 tonsDM/ha, whereas Quadrat number one in the same zone had the greatest plant biomass with an estimated 25.33 tonsDM/ha.

Table 1. Average aboveground biomass in woody species (tonsDM/ha) per vegetation zone. Values are means ± SD

Vegetation units	Biomass (KgDM/900 m^2)	Biomass (tonsDM/ha)
Average biomass in *Acacia seyal* zone	989.5 ± 655.70	10.99 ± 7.29
Average biomass in Woodland zone	1517 ± 586.50	16.87 ± 6.52
Average total biomass	1253.74 ± 657.55	13.93 ± 7.30

Aboveground biomass of trees in different vegetation units.

The average biomass per species per unit area and their sampling proportion are presented in appendix 3. It shows that in the *Acacia seyal* zone some plant species stored relatively more biomass per unit area than others, despite having an overall low density. These include *Balanites aegyptiaca* (2.183 tonsDM/ha, 1.5%) and *Acacia polyacantha* (1.411 tonsDM/ha, 0.5%), whereas other species such as *Acacia seyal* stored relatively low biomass per tree on average (0.387 tons/ha) but present a relative density as high as 83.5%. Based on their relative proportion in total sampling, *Acacia seyal* was the most important species followed by *Piliostigma reticulation*, *Combretum aculeatum, Ziziphus mauritiana, Balanites aegyptiaca, Crateva adansonii* and others. The woodland zone is characterized by a diversity of woody species of various proportions, each contributing to the aboveground biomass. The pattern of biomass in trees observed in the *Acacia seyal* zone is the same as in the woodland zone. Some trees species such as *Mytragimna inermis* or *Sclerocarya birrea* stored biomass per tree averaging 5.4206 tonsDM/ha respectively, but their overall proportion of total biomass is low. However, no tree appears to constitute a highly dominant feature in this vegetation zone.

Aboveground biomass in herbaceous species under different vegetation units

The results indicate a great variation in the aboveground biomass in herbaceous species throughout vegetation types ($F_{2,32}$ = 7.73, P = 0.002, R^2 = 33.3%, Table 2). On average, herbaceous biomass was greater in the floodplain zone than in the woodland zone, but did not differ significantly from that of the *Acacia seyal* zone (Table 2, Appendix 4). The breakdown of the herbaceous biomass per quadrat is presented in appendices 5, 6 and 7, where we can clearly see variation within vegetation type. Within the Floodplain zone (Appendix 4), the highest aboveground biomass of herbaceous species was found in quadrat 14 (11.67 tonsDM/ha) and the lowest was in quadrat 16 (3.87 tonsDM/ha).

Table 2. Average aboveground biomass in herbaceous species per unit area per vegetation zone. Values are means ± SD

Vegetation units	Biomass (KgDM/900 m^2)	Biomass (tonsDM/ha)
Herbaceous biomass in *Acacia seyal* zone	378.7726 ± 260.3815	4.208678 ± 2.893013
Herbaceous biomass in Woodland zone	235.3711 ± 171.3821	2.615257 ± 2.056842
Herbaceous biomass in Floodplain zone	621.1595 ± 247.2088	6.901801 ± 2.746803
Total herbaceous biomass	491.8293 ± 279.5963	5.46481 ± 3.153343

Overall productivity in trees and herbaceous species

The mean biomass production in trees and grasses per unit area was estimated at 13.863 ± 6.4 tonsDM/ha (Table 3). Averages of aboveground biomass in trees and grasses were 13.93 ± 4.16 tonsDM/ha and 4.58 ± 2.164 tonsDM/ha, respectively. Table 3 gives the contribution of each plant group to the average biomass production within different vegetation zones. Overall, the aboveground biomass was higher in the *Acacia seyal* zone and the woodland zone than in the Floodplain zone (Table 3).

Table 3. Mean aboveground biomass (tonsDM/ha) in trees and grasses per vegetation zone.

Vegetation units	Trees biomass	Herbaceous biomass	Total
Acacia seyal zone	10.99	4.209	15.199
Woodland zone	16.87	2.62	19.49
Floodplain zone		6.9	6.9
Mean ± SD	13.93±4.16	4.58± 2.164	13.863 ± 6.4

Discussion

This study is the first of its nature to examine the food supply for elephants in Cameroon and in the Central Africa region. Similar studies have been conducted elsewhere on birds [27], using equations relating invertebrate prey size and biomass. In this study, trees size was related to biomass using Brown's [5] allometric equations. We found that, compared to the *Acacia seyal* zone, the woodland zone had a higher aboveground biomass, most likely because of the larger diameter of the trees sampled there. Indeed, biomass per tree increases geometrically with diameter [5]. In his study, de Bie [13] used estimates of woody foliage biomass as indicators of wildlife food supply from trees; this makes comparison with our average aboveground biomass estimates challenging. We took into account all aboveground organic matter present in trees, including leaves, twigs, branches, main bole and bark, as they are all accessible or usable by elephants, depending on the environment. Our reported average aboveground biomass in trees of 13.93 tonsDM/ha is lower than the 20 tonsDM/ha of the degraded tree savannah of Burkina Faso and even lower than the 28 tonsDM/ha of the tree savannah of Gambia [5]. This is surprising given that the biomass estimates of these habitats in the other studies were based on trees with a minimum diameter at breast height of 10 cm, compared to a minimum of 1.5 cm for this study. This illustrates that the trees in the WNP do not have a large contribution to the park's biomass.

The comparison of the herbaceous layer in the three vegetation zones shows that this layer is most abundant in the floodplain zone and declines through the *Acacia seyal* zone and through to the woodland zone. This pattern follows the increase in canopy cover over these vegetation zones, which reduces light at ground level and suppresses herbaceous growth, as pointed out by Ouedrago [28]. Our estimate of the overall average biomass of herbaceous species, at 4.58± 2.164 tonsDM/ha, corresponds well with data from elsewhere in the Sudan savannah (Table 4). These data suggest that there are variations in the estimation of the total biomass of herbaceous plant production, which may be site specific due to differences in topography and soil type, in combination with the effect of local water infiltration and the spatial redistribution of water run-off [29, 30]. Specifically, these variations were related to the differences in topography and soil texture that affect the infiltration rate of rainwater [13], which may also be the case in our study area. Thus the differences in soil type, ranging from sandy to compact clay soil in the woodland zone, to black clay soil in the *Acacia* zone and hydro-morphed soil in the floodplain, may also account for much of the local variation found in the biomass production of herbaceous plants in the WNP. Finally, rainfall alone does not determine the total aboveground biomass of plant production; factors like nutrient availability influence aboveground biomass of plant production, and might also influence their value for elephants or other herbivores.

We were not able to provide firm numbers for the carrying capacity for elephants or other large herbivores in the park from our study due to its limited scope. However, with an estimated population just below 500 individuals [1] combined with seasonal migration patterns showing only about half of the elephant population remaining permanently in the park, there may already be a mismatch between the elephants' population size and their habitat, calling for close monitoring of their activity to be implemented. Clearly, water and forage being the most limiting factors in the park, their use by elephants should be monitored in order to determine a realistic carrying capacity.

The actual harvestable food supply for elephants is much less than the estimated aboveground biomass. Several factors influence the available phytomass. Indeed, factors like fire, drought, and extreme temperatures account for most of the variations in aboveground biomass, which was observed within our study when comparing quadrats from the different vegetation types. In the wet and early dry season, grazing herbivores have three to four times more phytomass to feed on than browsing herbivores, however this amount changes towards the end of the dry season [13]. However, bush fires in the dry season remove high amounts of aboveground biomass, which is then unavailable to the herbivores of the savannah, changing the distribution of available food sources for the grazers and browsers in the park. For example, just after these fires, there may be more woody foliage to browse than there is grass to graze. This observation is supported by the biomass pattern of trees and herbaceous species, where trees contribute more than 70% of the aboveground biomass in the study area. The scale of these changes, especially concerning the quantity of available forage, strongly determines the long-term suitability of certain areas for sustaining viable populations of herbivores, including elephants [13]. Differences in body mass, together with the available food resources in an area, could determine the size of each population of herbivores [31].

We concluded that in our study area, where mean annual rainfall varies between 600-800 mm per annum, an estimated average aboveground biomass of biomass of 13.87 tonsDM/ha was potentially available to elephants and other herbivores. The actual harvestable food supply for elephants will certainly be a small fraction of this estimate, however this estimated value is higher than in other areas with similar rainfall. It appears that rainfall alone cannot determine the level of forage production; differences in topography and soil texture may also be important factors. The highest level of forage herbaceous biomass production was found in the floodplain zone, due to greater canopy cover reducing the herbaceous layers in the other two vegetation zones. The tree biomass was higher in the woodland zone than in the *Acacia seyal* zone due to larger sized trees in the woodland zone increasing the total biomass.

Our findings may partly explain the migratory status of at least some of the individuals leaving the park every year and returning to the WNP in a potentially seasonal migratory pattern. Water availability and distribution were reported to be the most important factors influencing elephant movements in WNP [4], making the *Acacial seyal* vegetation zone, with two artificial waterholes, the best available habitat during the dry season. However it was also noted that vegetation types such as the woodland savanna, which are normally avoided during the dry season, were utilized to a greater extent by elephants during the wet season. These findings indicate that estimates of carrying capacity for elephants will have to take into account ecological factors such as water availability, and nutritional values of trees and grasses.

Implications for conservation

It has been highlighted that during the beginning of the dry season, many elephants break out of the WNP and migrate to Kalamaloue National Park, Cameroon [3]. Whether this is due to food scarcity inside the park is still to be confirmed, however when they leave the park the elephants roam the neighbouring cultivated fields, damaging local people's crops. The traditional management of WNP has consisted mainly of the early bush fires and rehabilitation of water holes, but this has appeared insufficient for its elephant population. These management tools should be reinforced and developed by increasing the number of waterholes and ensuring that the population size is suitable for the current habitat. Recent researches suggest that a combination of approaches, taking into account the ecological and biological needs of elephants [14, 32], must be implemented for a better management and conservation plan. Indeed, a conservation strategy, incorporating both Waza and Kalamaloué national parks linked by a 'corridor' including areas south of Waza, will benefit both elephants and humans, and will ensure the sustenance of a healthy elephant population in WNP for the future.

To manage WNP's habitat properly, habitat conditions must be improved to enable the elephant population to acquire most of its forage from natural feeding sources inside the park, rather than turn to croplands adjacent to the park. The estimated plant biomass represents an average for the entire dry season in the study area. This estimated value is more useful for long-term planning purposes than for predicting dry-season forage production in particular years. It is understood that in years of extreme climatic conditions (e.g. severe drought), the situation may be different, with a reduced biomass available to the elephants. Continuous measurements of forage production during this critical period of the year, as well as during wet seson, is necessary to generate a database to make long-term predictions of forage production in the WNP, and in order to suggest the number of elephant and other wild herbivores that the park could sustainably support.

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References

[1] Foguekem, D., M.N. Tchamba and P. Omondi. 2010. Aerial survey of Elephants (*Loxodonta africana africana*), other large mammals and human activities in Waza National Park, Cameroon. *African Journal of Environmental Science and Technology* 4:401–411.

[2] Tchamba, M.N. & Elkan, P. 1995. Status and trends of some large mammals and ostriches in Waza National Park, Cameroon. *Afr. J. Ecol*. 33:366-376

[3] Tchamba, M.N. Bauer, H. De Iong H. 1995. Application of VHF radio and satellite telemetry techniques on elephants in northern Cameroon. *African Journal of Ecology* 33:335-346.

[4] Tchamba M.N. 1996. Elephants and their interactions with People and vegetation in the Waza-Logone Region, Cameroon. PhD thesis, Amsterdam, The Netherlands.

[5] Brown S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134. 55pp, Rome, Italy, FAO.

[6] Metcalfe, N.B., Fraser N.H.C., Burns, M.D. 1999. Food availability and the nocturnal vs. diurnal foraging trade-off in juvenile salmon. *Journal of Animal Ecology* 68:371-381.

[7] Ball, J.P., Danell, K. and , Sunesson P. 2000. Response of a herbivore community to increased food quality and quantity: an experiment with nitrogen fertilizer in a boreal forest. *Journal of Applied Ecology* 37:247-255.

[8] Fryxell, J.M. 1991. Forage quality and aggregation by large herbivores. *American Naturalist* 138:478-498.

[9] Belovsky, G.E. 1981. Food plant-selection by a generalist herbivore - the moose. *Ecology* 62:1020-1030.

[10] Houston, D.B. 1982. The Northern Yellowstone elk: Ecology and management. New York: Macmillan publishing company.

[11] Sinclair, A.R.E. and Nortongriffiths, M. 1982. Does competition or facilitation regulate migrant ungulate populations in the serengeti - a test of hypotheses. *Oecologia* 53:364-369.

[12] Dublin, H.T., Sinclair, A.R.E., Boutin, S., Anderson, E., Jago, M, and Arcese, P. 1990. Does competition regulate ungulate populations - further evidence from serengeti, tanzania. *Oecologia* 82:283-288.

[13] de Bie, S. 1991. Wildlife resources of the West African savanna. PhD thesis, Wageningen, The Netherlands: Agricultural University.

[14] Foguekem D., Tchamba, M.N., Gonwouo, L.N., Ngassam, P. and Loomis, M. 2011. Nutritional status of forage plants and their use by elephant in Waza National Park, Cameroon. *Scientific Research & Essay* 6:3577-3583

[15] Field, C.R. 1976. Palatability factors and nutritive values of the food of buffaloes (Syncerus caffer) in Uganda. *East African Wildlife. J*. 14:181-201.

[16] Van Soest, P.J. 1982. Nutritional ecology of ruminants. Cornell University Press, P. 373.

[17] De Iongh, H.H. 1996. Plant-Herbivore Interactions between Seagrasses and Dugongs in a Tropical Small Island Ecosystem. PhD Thesis,University of Wageningen P. 205

[18] Ruggiero, R.G. 1992. Seasonal forage utilization by elephants in central africa. *African Journal of Ecology* 30:137-148.

[19] Pfeffer, P. 1989. Vie et mort d'un geant: l'éléphant d'Afrique.: Flammarion, France, 191pp.

[20] Loth, P. (Ed), 2004. The Return of the Water: Restoring the Waza Logone Floodplain in Cameroon. IUCN, Gland, Switzerland and Cambridge, UK. xvi + 156 pp.

[21] Gee, J.H.R. 1988. Population-dynamics and morphometrics of *Gammarus-pulex* l - evidence of seasonal food limitation in a fresh-water detritivore. *Freshwater Biology* 19:333-343.

[22] Butynski, T.M. 1990. Comparative ecology of blue monkeys (Cercopithecus-mitis) in high-density and low-density subpopulations. *Ecological Monographs* 60:1-26.

[23] Skogland, T. 1985. The effects of density-dependent resource limitations on the demography of wild reindeer. *Journal of Animal Ecology* 54:359-374.

[24] Floret, C. 1988. Methodes de mesure de la végétation pastorale. Institut Agronomique et Veterinaire Hassan II Rabah-Maroc & Institut mediterraneen de Montpellier-France, 150pp.

[25] Billé, J.C. 1980. Measuring the primary palatable production of browse plants. In *Browse in Africa.* Lehouérou, H.N. (ed.), pp 183-193. ILCA, Addis Abeba, Ethiopia.

[26] Parresol, B.R. 1999. Assessing tree and stand biomass: A review with examples and critical comparisons. *Forest Science* 45:573-593.

[27] Masero, J.A., Perez-Gonzalez, M., Basadre, M. and Otero-Saavedra, M. 1999. Food supply for waders (Aves : Charadrii) in an estuarine area in the Bag of Cadiz (SW Iberian Peninsula). *Acta Oecologica-International Journal of Ecology* 20:429-434.

[28] Ouedrago, P.M. 1985. Etude de la relation herbe-arbre dans une savane naturelle Soudanienne : phytosociologie et phytomass maximale dans divers faciès de savane plus ou moins dense de la réserve de Nazinga (Burkina Faso). Mémoire du diplôme d'ingénieur des techniques du développement rural: Université de Ouagadougou, Burkina Faso.

[29] HilleRisLambers, R., Rietkerk, M., van den Bosch, F., Prins, H.H.T. and de Kroon, H. 2001. Vegetation pattern formation in semi-arid grazing systems. *Ecology* 82:50-61.

[30] Hernaux, P. 1980. L'inventaire du potentiel fourrager des arbres et arbustes d'une region du sahel Malien: methodes et premiers resultats. In *Browse in Africa.* Lehouérou, H.N. (ed.), pp195-201. ILCA, Addis Abeba, Ethiopia.

[31] Oindo, B.O., Skidmore, A.K. and Prins, H.H.T. 2001. Body size and abundance relationship: an index of diversity for herbivores. *Biodiversity and Conservation* 10:1923-1931.

[32] Tchamba, M. N. and Foguekem, D. 2012. Human Elephant Conflict in the Waza-Logone Region of Northern Cameroon: An Assessment of Management Effectiveness. *Tropicultura* 30:79-87.

[33] Bourliere, F. and Hadley, M. 1970. The ecology of tropical savannas. *Annual Review of Ecology and Systematics* 1:125-152.

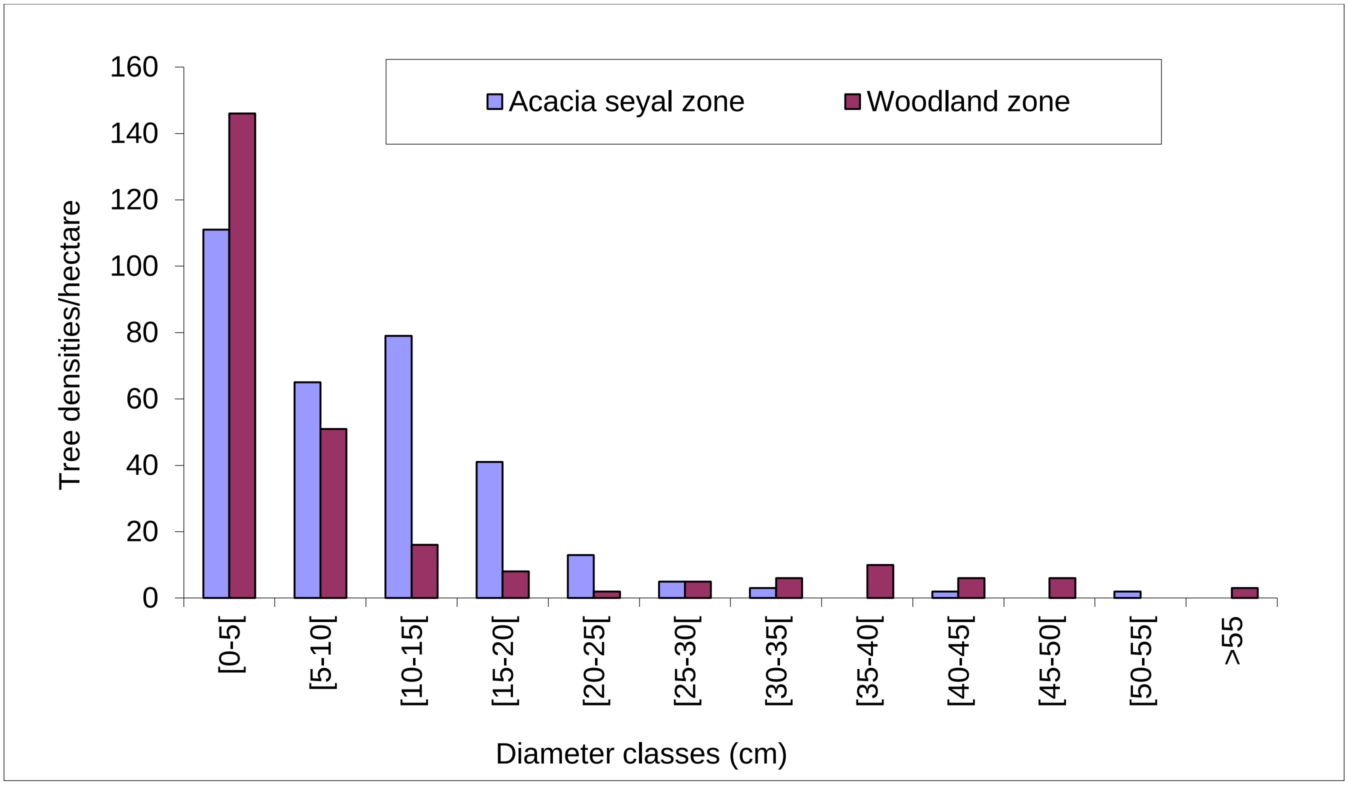
[34] Breman, H. and Dewit, C.T. 1983. Rangeland productivity and exploitation in the sahel. *Science* 221:1341-1347.

[35] Fournier, A. 1982. Cycle saisonnier de la biomasse herbacéedans les savanes de Ouango-Fitini. *Ann. Univ. Abidjan, Ser. E (Ecol.)* 15:63-94.

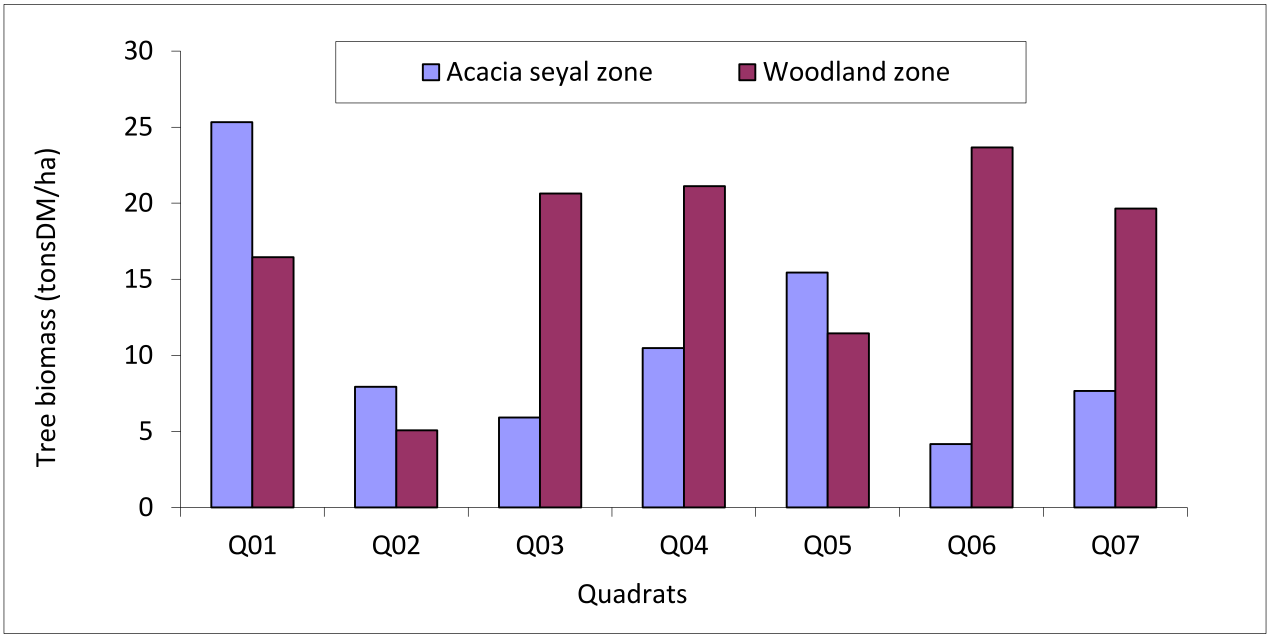
[36] Fournier, A. 1987. Cycle saisonier de la production herbacéedans les savanes soudaniennes de Nazinga (Burkina Faso).Comparaison avec d'autres savanes ouest-africaines. *Bull. Ecol* 18:409-430.

[37] UNESCO 1979. Tropical grazing land ecosystems. Natural resources research vol XVI. UNESCO, Paris, France:

Appendix 1. Graphic showing diameter class distribution of trees per unit area (ha).



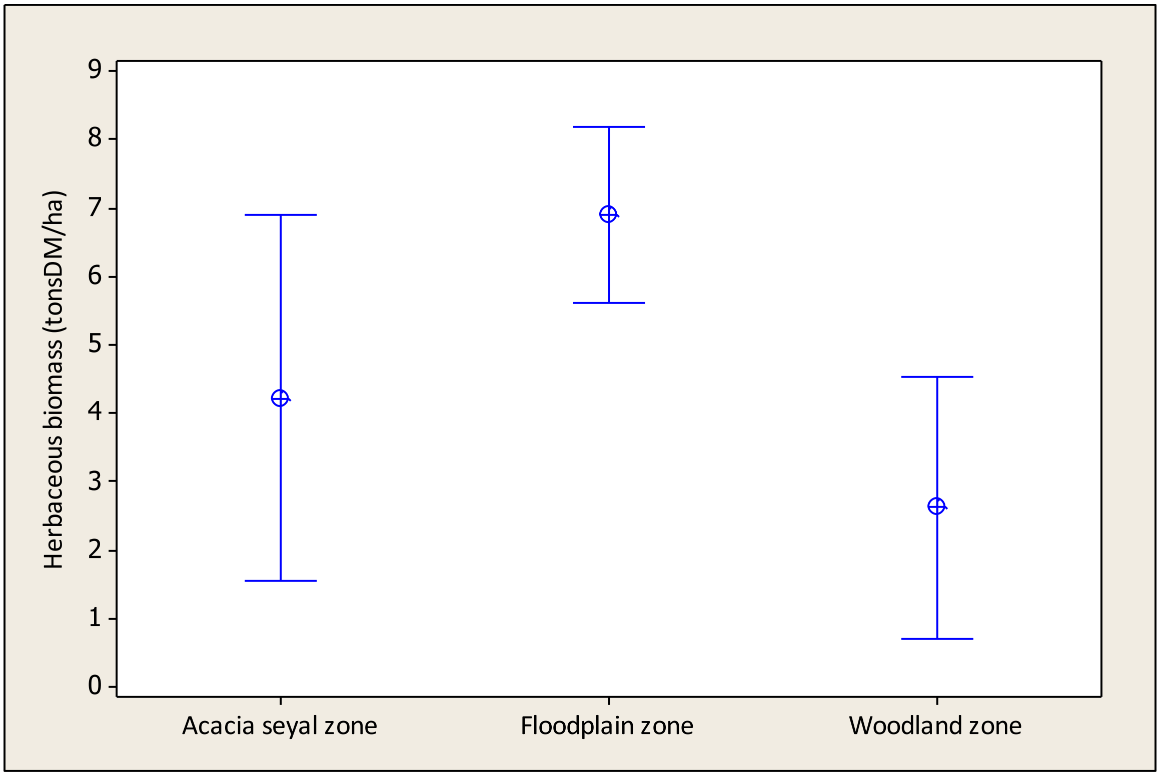
Appendix 2. Aboveground biomass in trees per quadrat in *Acacia seyal* and woodland zone.



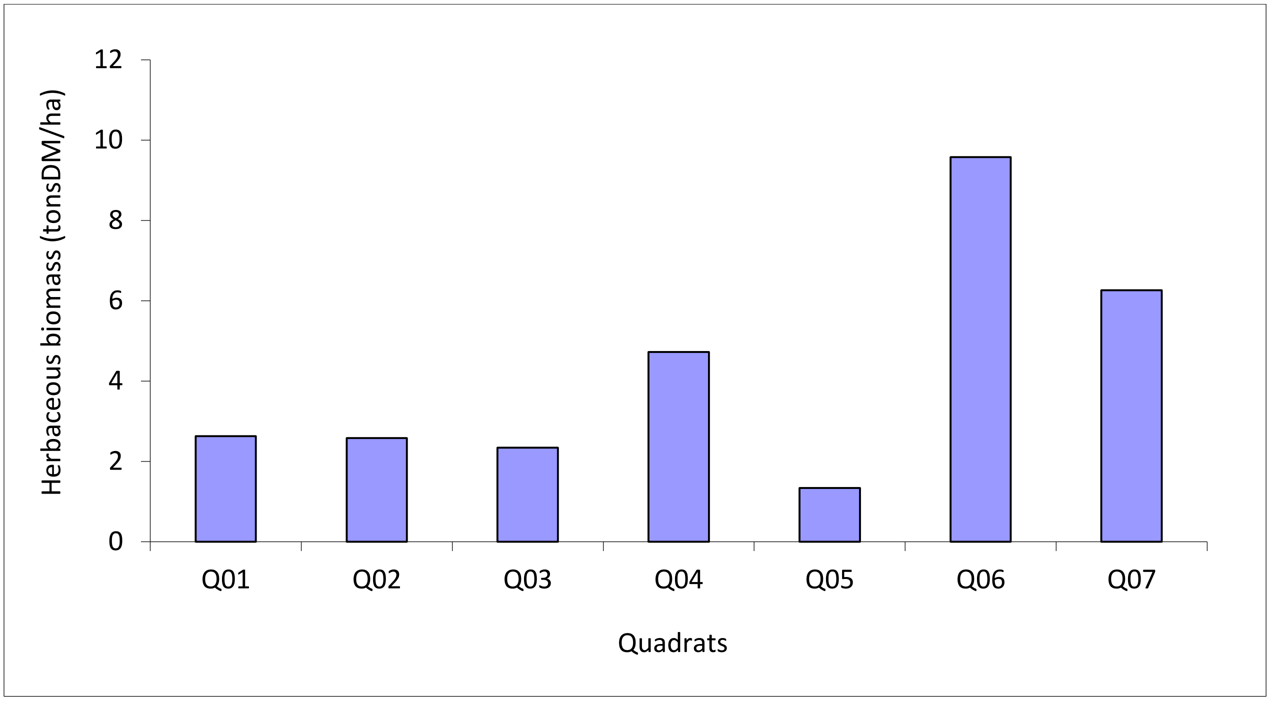
Appendix 3. Average biomass in plant (tonsDM/ha) under different vegetation zone and the proportion of each plant species.

	***Acacia seyal* zone**				**Woodland zone**			
	Average biomass				Average biomass			
Plant species	Minimum	Mean	Maximum	Relative frequency	Minimum	Mean	Maximum	Relative frequency
Acacia polyacantha	1.411	1.411	1.411	0.5%				
Acacia athaxacantha					0.0092	0.0288	0.058	1.9%
Acacia seyal	0.00313	0.387	4.391	83.5%				
Acacia sieberiana					0.031	0.0374	0.044	1.2%
Anogeissus leiocarpus					0.260	2.378	4.223	4.3%
Balanites aegyptiaca	0.002483	2.183	6.362	1.5%	0.000855	0.562	3.59	6.2%
Boscia senegalensis					0.0092	0.0092	0.0092	0.6%
Cadaba farinose	0.037	0.037	0.0037	0.5%	0.00104	0.012	0.0311	6.2%
Capparis thomenthosa	0.0092	0.0092	0.0092	0.5%	0.00234	0.0142	0.0208	2.5%
Capparis sp	0.0164	0.0164	0.0164	0.5%				
Celtis integrifolia					0.035	0.035	0.035	0.6%
Combretum aculeatum	0.00651	0.02	0.044	3.0%	0.000587	0.03072	0.412	21.0%
Combretum collinum					0.4124	0.67	0.93	1.2%
Combretum glutinosum	0.1612	0.1612	0.1612	0.5%	0.0260	0.1213	0.372	6.2%
Cratera adansonii	0.044	0.1622	0.2805	1.0%	0.1135	0.1382	0.163	1.2%
Diospiros mespiliformis					0.00043	0.00043	0.00043	0.6%
Feretia apodentera					0.000104	0.039	0.093	6.2%
Gardenia ternifolia					0.00651	0.00651	0.00651	0.6%
Grewia sp					0.0312	0.0312	0.0312	0.6%
Guiera senegalensis					0.00104	0.0783	0.298	10.5%
Hyphaena thebaïca					0.1033	0.1033	0.1033	0.6%
Kigelia africana					3.3	3.3	3.3	0.6%
Lannea humilis					0.001042	0.1307	0.1037	4.3%
Maerua sp					0.093144	0.093144	0.093144	0.6%
Mytragimna inermis					0.78	7.7	14.605	1.2%
Piliostigma reticulatum	0.00433	0.180	0.07503	6.0%	0.02605	0.4351	1.776	6.8%
Sclerocarya birrea					0.0701	5.4206	14.36	5.6%
Securinega virosa					0.037	0.037	0.037	0.6%
Stereospermum kunthianum					0.188	1.86	3.84	3.1%
Tamarindus indica	0.4499	0.4499	0.449	0.5%	2.79	2.79	2.79	0.6%
Terminalia avicenoïdes					0.058	0.096	0.149	2.5%
Trema guineensis					0.535	0.535	0.535	0.6%

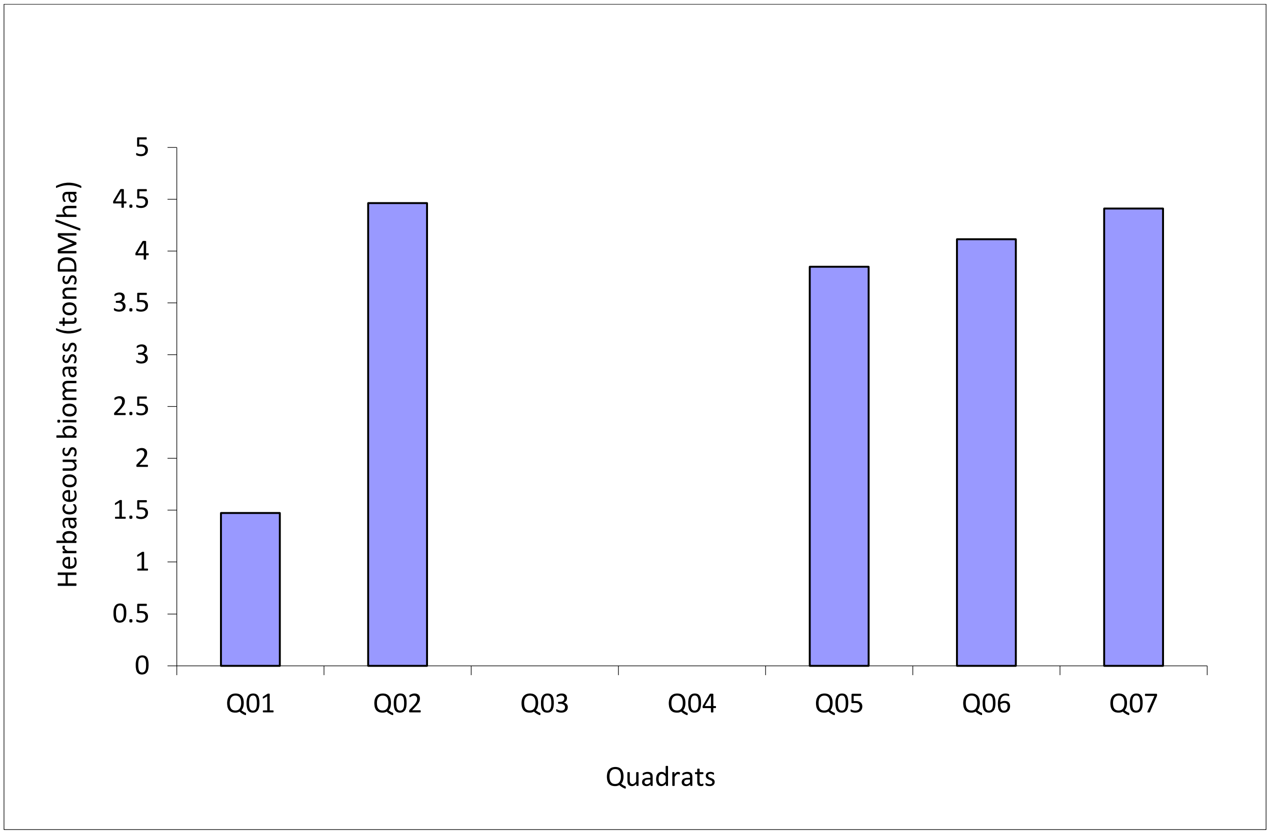
Appendix 4. Differences in herbaceous biomass between the three vegetation types (*Acacia seyal* zone, Floodplain zone and woodland zone). Values are mean ± 95% confidence interval.



Appendix 5. Aboveground biomass in herbaceous species per quadrat sampling in *Acacia seyal* zone.



Appendix 6. Aboveground biomass in herbaceous species per quadrat sampling in woodland zone.



Appendix 7. Aboveground biomass in herbaceous species per quadrat sampling in floodplain zone.