The environment and vegetation of the flux measurement site near Skukuza, Kruger National Park

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The SAFARI-2000 intensive study site is located 13 km WSW of Skukuza. Detailed measurements of the exchanges of energy, water, carbon dioxide and other substances between the savanna and the atmosphere have been made there since April 2000. This paper provides basic information regarding the climate, soils and vegetation at the site. The site is located near the top of a gentle rise in an undulating granitic landscape. Most of the data were collected within a 300 m square centred on the flux tower situated at 25°01.184' S, 31°29.813' E and oriented true north. The tower stands exactly on the ecotone between a ridgetop broad-leafed *Combretum* savanna on sandy soil and a midslope fine-leafed *Acacia* savanna on clayey soil. The ecotone is marked by a 10 m wide band of sedges. The tree basal area within the sample square was 6.8 m^2/ha (± 1.0 standard error), the tree density 128 ± 16 plants/ha and the tree crown cover 24 ± 4 %. Shrubs, defined as woody plants greater than 0.5 m but less than 2.5 m tall, contributed a further 7.6 % crown cover. The basal area weighted mean height of the trees was 9 m, and the maximum height 13 m. Nineteen woody plant species were recorded within the square, with 70 % of the woody plant basal area dominated by *Combretum apiculatum*, *Sclerocarya birrea* and *Acacia nigrescens*. The rooted basal area of grasses was 7.1 ± 0.6 % and in June 2000 the grass standing crop was 400 g DM m^2.

Key words: basal area, climate, crown cover, savanna, soil, tree density.

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Introduction

The SAFARI-2000 experiment aims to understand and quantify the interactions between the atmosphere and the land surface in southern Africa. Part of the experimental programme involves measurement of exchanges ('fluxes') of energy, water, carbon dioxide and other gases and aerosols between the atmosphere and the land surface. These measurements are being conducted at a few micrometeorological towers located to represent broad classes of vegetation. One such tower has been erected 13 km WSW of Skukuza in the Kruger National Park (Fig. 1). It was deliberately placed on a vegetation transition ('ecotone') in order to sample different vegetation types with different wind directions. The measurement 'footprint' of the eddy covariance instruments, mounted at 17 m on the tower, reaches about 600 m upwind.

The SAFARI-2000 experiment makes extensive use of the TERRA-AM satellite platform, the first of a new generation of Earth Observing Satellites, launched by NASA in December 1999. This platform carries several sensors, all of which require calibration and validation. The Skukuza site is one of a

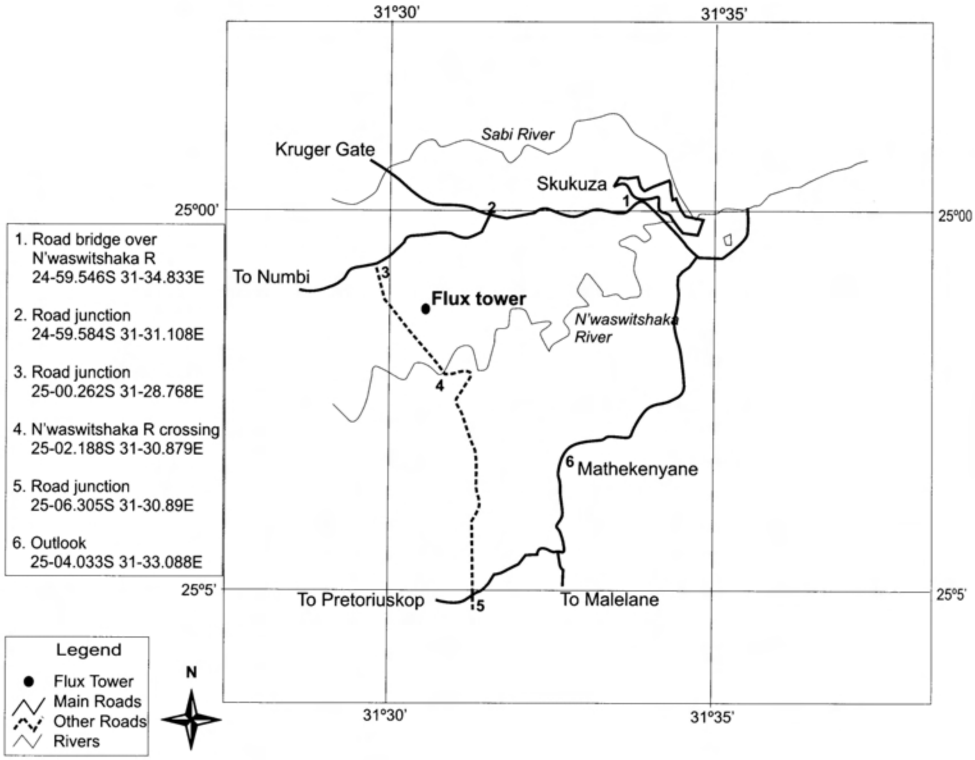

Fig. 1. The location of the SAFARI-2000 flux measurement site near Skukuza. It is in the N'waswitshaka Cathment, a non-perennial tributary of the Sabie River. The nearest tourist road (S61) is 1 km to the west of the site. It has a gravel surface and carries light daytime traffic, and is thus not expected to influence readings at the site. Site access is via a track leading off the S61, 2.5 km south of the junction with the tarmac H-6.

network of similar sites, chosen to represent the major biomes of the world and designed to assist with the calibration of the MODerate resolution Imaging Spectrometer (MODIS) instrument. MODIS has a best resolution of 250 m x 250 m, which requires that site information be collected at least at this scale. MODIS is unique in the range of standard products it plans to deliver: not only spectral images in 32-wavelength bands, but also maps of the aerosols in the atmosphere, the leaf area index on the ground, the net primary productivity of the land surface and the occurrence of fires. The validation sites are therefore equipped with instruments to measure incoming and outgoing radiation, atmospheric aerosol thickness and size, soil, canopy and air temperature, soil water content, rainfall, and the vertical fluxes of water vapour and carbon dioxide on a continuous basis. The seasonal progression of leaf area will be monitored on a monthly basis using hand-held instruments and high-resolution digital aerial photography. This programme of data collection will continue for several years, and perhaps longer.

The many scientists, who will use data from the Skukuza site, will require basic information on the environment and vegetation in order to interpret their observations. It is the purpose of this paper to provide that information.

The study site

The Skukuza flux site is within the Kruger National Park (KNP), a 2 million ha area managed for wildlife conservation for the past century. It is 10 km south of the Sabie River, which marks the nearest park boundary. Outside of the park, the land use includes orchards of tropical fruits, croplands, private game reserves, cattle grazing and areas of human settlement. The tower is located in management block S31 at an altitude of 365 m above sea level.

Geology, geomorphology and soils

The site is located towards the western edge of the 'lowveld', a broad coastal plain at around 300 m above sea level. The foothills of the escarpment, which marks the edge of the 2000 m-high interior plateau known as the 'highveld', lie approximately 30 km to the west. The Indian Ocean is 140 km to the east, with the low Lebombo hills, which mark the border between South Africa and Mozambique (and the eastern edge of the park), in between.

The geology underlying the site is Archaean granite and gneiss of the Nelspruit suite, (Barton *et al.* 1986), with frequent narrow doleritic dykes and some migmatite intrusions. This gives rise to a characteristically undulating landscape, with drainage lines about 3 km apart, and ridge tops about 40 m above the valley floors. Venter (1990) classifies it as Skukuza land type Sk7. Illuviation of clay down the gentle slopes leads to a very distinctive catenal pattern in the soils and vegetation (Chappell 1992). The ridgetop soils are generally less than 0.8 m deep and sandy (Clovelley, Hutton and Glenrosa forms are characteristic; luvisols in the FAO classification and a typic ustalf in USDA terms). The presence of appreciable amounts of sodium feldspar in the parent material leads to deflocculation of the clays, which are transported by sub-surface water movement and accumulate a few hundred metres downslope of the crest. In high rainfall years, any water draining downslope through the soil profile is forced to the surface by this impervious clay layer, forming a temporary perched water table known as a seepline. Below the seepline the soils are clayey and fertile, often duplex (Estcourt and Sterkspruit forms; solonetz in FAO, natrustalfs in USDA) and sometimes vertic (Mayo form; a vertisol in the FAO and USDA classifications). Generally the clay soils are a metre or more in depth, but at the study site they seldom exceed 0.6 m anywhere. The catenal sequence may repeat itself several times down a long slope, before terminating in alluvial soils near the drainage line. Typical soil analyses for the landscape (not necessarily the site) are given in Table 1.

Climate

The climate is semi-arid subtropical, with the hot, rainy summers and warm dry winters characteristic of areas supporting savanna vegetation. The climate statistics for Skukuza are presented in Table 2. Since 1916, when regular observations began at Skukuza, the temperatures have risen by about 0.05 °C/decade. There is no detectable trend in the rainfall, but evidence of a cycle with a period of approximately 18 years in the annual July to June rainfall totals (Tyson & Dyer 1975; Gertenbach 1980). Annual rainfall totals are approximately normally distributed. Over the brief period of temperature measurement at the site (since April 2000), the air temperature at 17 m is on average 0.5 °C cooler than the 2 m screen temperature at the weather station at Skukuza, due to the slightly higher altitude. The long-term rainfall would be expected to be a few percent higher at the site than at Skukuza, since rainfall increases towards the west.

Vegetation

The broad-scale vegetation map of South Africa (Low & Rebelo 1996) describes the vegetation of the region as 'mixed lowveld bushveld'. The KNP landscape classification of Gertenbach (1983) includes it with the 'Sabie and Crocodile River thickets', although the actual site vegetation is structurally too tall and too open to qualify as a thicket. The detailed phytosociological classification of the central KNP by Coetzee (1983) covers only the area north of the Sabie River, but the crest vegetation at the site would be very similar to the 'Brushveld and Treeveld with *Terminalia sericea*, *Pterocarpus rotundifolius* and *Setaria flabellata*' community, and the midslope to the 'Brushveld and Treeveld with *Acacia nigrescens*, *Oropetium capense* and *Eragrostis superba*' described by him.

The catenal pattern is very clearly reflected in both the woody vegetation and the herbaceous layer. The sandy uplands are dominated by *Combretum apiculatum*, with fibrous, low palatability grasses such as *Pogonarthria squarosa* and *Perotis patens* common in the herbaceous layer. This vegetation is representative of the 'broad-leafed' savannas occurring in relatively dry, infertile situations throughout southern Africa (Coetzee & Werger 1978; Scholes 1997). It is not representative of the moist broad-leafed, infertile 'miombo' woodlands of south Central Africa, which will be sampled at the SAFARI-2000 site near Mongu, western Zambia.

The seeplines in this landscape are usually marked by a band of *Terminalia sericea* trees, but not obviously so in this case. On the seepline there is a conspicuous presence of sedges (Cyperaceae) in the herbaceous layer for a width of about 10 m. On the

Table 1

Soil analyses from granitic catenas in the southern Kruger National Park

These data should be regarded as broadly representative of the landscape, rather than the exact values for the site itself. Sampling and analysis is in progress for the site, and will be reported separately. a) Physical parameters. -33 is the water content at θ–33 kPa tension ('field capacity') and -1500 is the water content at θ –1500 kPa ('wilting point'). b) Chemical parameters. CEC is the cation exchange capacity, SAR is the sodium adsorption ratio and OC is the organic carbon content. The main data are for profiles described by Chappel (1992), supplemented with data from elsewhere.

a)

Depth mm	sand %	silt %	clay %	Bulk density Mg/m^3	Gravel[a] %	K sat[a] m/s x 10^{-6}	θ –33[b] v/v	θ -1500[b] v/v
Clovelly form: ridge crest soils								
0 – 300	69	5	26	1.71	9.84	2.26	0.12	0.06
300 - 600	69	5	26	1.68	14.33	2.64	0.13	0.07
Estcourt form: midslope soils								
0 – 300	69	6	25	1.68	5.19	0.52	0.20	0.10
300 - 600	65	3	32	1.74	1.82	0.01	0.21	0.11

b)

Depth mm	Ca^{2+} cmol (+) /kg[a,c]	Mg^{2+}	K^+	Na^+	SAR	CEC	pH (1:2.5 H_2O)	Extr P[c] mg/kg	Total N[d] mgN/kg	OC[e] %
Clovelly form										
0 – 300	1.71	8.71	0.16	4.72	2.07	15.3	5.18		450	1.9
300 - 600	1.04	0.59	0.18	0.83	1.02	2.34	7.88			
Estcourt form										
0 – 300	0.57	10.93	0.03	16.33	6.02	30.75	5.22	15	935	
300 - 600	4.23	0.36	0.04	35.80	23.63	40.43	7.19	7		

Notes

[a] Chappell (1992), sites in similar landscapes about 20 km further north. Venter (1990) gives the breakdown of the sand fraction for a Sterkspruit form soil in the Skukuza land type as 11, 17, 20, 10 and 7% very coarse, coarse, medium fine and very fine sand respectively.

[b] Scholes (1987), granite-derived soils 100 km north of the site.

[c] Venter (1990).

[d] Data from Parsons *et al.* (1996) for the fire plots at Shabeni, 30 km to the south, and for plots on gabbro 7 km from Shabeni, for the clayier soils.

[e] Levine *et al.* (1996) for the plots at Shabeni, 30 km to the south.

clayey soils below the seepline, the tree layer is dominated by *Acacia nigrescens*—the geometry of the 300 x300 m sample area around the tower at this site indicates dominance by *A. nilotica*, however the broader landscape has much more *A. nigrescens*—and the grass layer by palatable species such as *Panicum maximum* and *Urochloa mossambicensis*. This community represents the arid, fertile 'fine-leafed' savanna type, widespread in southern Africa. The large tree *Sclerocarya birrea* is prominent in both the crest and midslope communities, and dominates this site overall.

Table 2

Climate statistics for Skuzuza for the period 1960 to 1999 (except humidity, which is for 1978 to 1999). The weather station is located at 24°59'S 31°36'E, altitude 263 m. Source: South African Weather Bureau. See also Gertenbach (1980) and SAWB (1986)

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean min temp (°C)	20.6	20.4	19.1	15.4	10.0	5.6	5.7	8.7	12.8	16.0	18.1	19.7	14.3
Mean max temp (°C)	32.6	32.0	31.2	29.4	27.9	25.9	25.9	27.3	29.3	29.8	30.6	31.9	29.5
Abs min temp (°C)	7.2	7.2	7.6	3.3	0.9	-4.4	-3.8	-4.2	1.1	6.5	6.7	2.0	-4.4
Abs max temp (°C)	43.0	43.0	42.0	40.0	38.1	35.3	36.1	38.5	42.0	43.6	44.5	44.4	44.5
Mean rainfall (mm)	92.9	87.4	73.2	33.2	13.5	9.5	10.4	6.2	25.7	34.9	75.9	84.3	547.1
Abs max rainfall (mm)	329	303	210	97	66	110	132	72	193	160	171	195	832
Abs min rainfall (mm)	11	1	4	0	0	0	0	0	0	4	7	12	345
Rainy days (days)	8.6	8.0	7.3	4.9	2.7	2.3	2.0	1.8	3.0	6.2	9.4	8.6	64.8
Mean storm size[a]	9.9	10.2	7.7	6.7	4.7	4.7	5.5	3.8	7.2	6.0	6.8	9.9	7.8
SD of storm size	16.1	17.3	12.3	9.9	7.8	8.4	12.6	5.9	14.5	8.5	9.8	14.0	12.9
Median storm size	3.8	3.0	2.8	2.7	1.4	1.0	1.5	2.0	1.9	2.0	2.8	4.5	2.7
Pr(R)|(R)x1000	4835	5126	4339	4000	3250	2651	3136	3224	4046	4723	5000	4698	4485
Pr(D)|(D)x1000	7615	7714	7859	8613	9295	9472	9598	9459	9242	8473	7316	7530	8634
Wind speed (m/s)	1.3	1.3	1.1	0.8	0.7	0.7	0.8	1.0	1.3	1.5	1.4	1.3	1.1
Humidity 14:00 (%)	52.8	52.4	51.8	47.7	42.7	37.5	39.6	38.2	41.3	44.3	49.9	50.4	45.7
Evaporation[c] (mm/d)	6.1	5.9	5.5	4.5	4.1	3.6	3.6	4.3	5.3	6.6	5.5	5.9	1848
Radiation (MJ/d)[b]	20.86	21.20	19.13	17.43	15.09	14.17	14.82	15.75	17.43	18.29	19.08	21.27	17.88
Sunshine hours (h/d)	7.4	7.7	7.4	7.7	8.0	8.1	8.2	8.2	8.0	7.4	6.9	7.1	7.7

Notes

[a] The rainy days, mean, standard deviation and skewness of storm size, Pr(R)|(R) (the probability of rain, given that it rained the previous day) and Pr(D)|(D) (probability dry, given that it was dry the day before) are needed to construct a daily rainfall simulator for the site.

[b] The global (ie direct plus diffuse) shortwave radiation received on a level surface is for Nelspruit, 100 km to the SW. The sunshine hours are for Skukuza.

[c] Evaporation is calculated using the Penman-Monteith equation (Louw & Kruger 1968).

Disturbance regime

The Kruger National Park is subject to a burning regime intended to mimic pre-colonial conditions. The fire policy changed during the 1990s, from one of burning in rotation approximately once every 3 years in late winter or early spring, to allowing naturally ignited fires to burn unhindered, while suppressing human ignited fires. Over the past 40 years, the mean return time between fires has been about 10 years for the park in general (Van Wilgen *et al.* 1998), but about 6 years in the block in which the tower is located. The most recent burn was 30 September 1996 and before that on 24 July 1985, 22 September 1981 (patchy, low intensity), 13 March 1976 (failed, fuel too wet), 12 December 1972 (accidental), 19 November 1968 and 15 November 1961. Fires consume the herbaceous layer and scorch the shrub layer, but have little impact on the trees.

Grazing and browsing ungulates are abundant. Six species of grazing ungulate (for this purpose, elephants and impalas are classified as 50 % grazers, 50 % browsers) are common in the site region, with a biomass density of about 1800 kg live weight/km^2. They are estimated to consume 20 g/m^2 of grass per year. Five species of browsers contribute 400 kg/km^2 of biomass, and consume about 5 g/m^2 of tree leaf material per year. The biomass of invertebrate herbivores is unquantified. Total invertebrate herbivory is probably higher than vertebrate herbivory.

The 'mega-herbivores', and particularly elephants, deserve a special mention because of their role in modifying savanna structure by pushing over trees. The elephant population, high in the early nineteenth century, was close to zero in 1903 as a result of hunting. It had built up to around 8000 by 1960. The KNP maintained an overall elephant density of 0.4/km^2 until 1995 by culling about 600 per year. The policy is now to allow the population to increase, while keeping a watch on the vegetation impact. The stem size distribution of *Sclerocarya birrea* in the site suggests strong recruitment fifty or more years ago, and no current recruitment. This pattern may be related to elephant densities.

Prior to about 1920, the KNP was sparsely populated by agro-pastoralists. The study site may coincide with an old settlement, as evidenced by the unusually high proportion of *Acacia nilotica* and some round stones reminiscent of grinding stones.

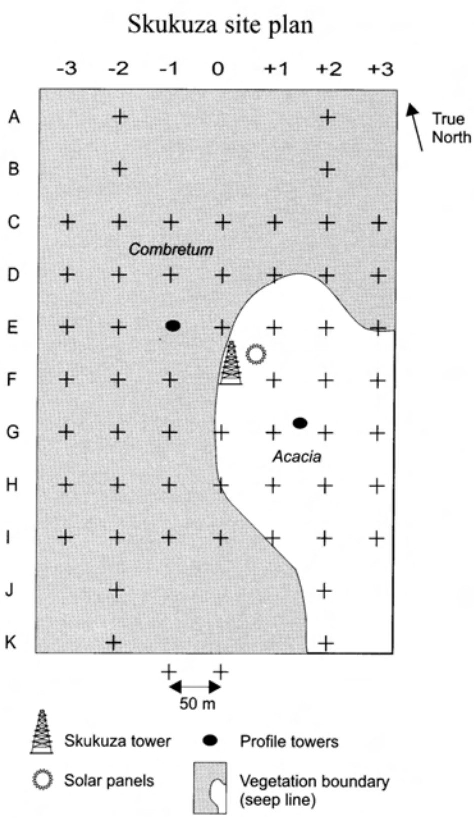

Fig. 2. The layout of the sample grid around the flux measurement tower.

Methods

The flux tower footprint and the MODIS pixel size required that the vegetation be sampled at a scale of several hundred metres, rather than the few tens of metres as is normal practice. A square grid of 49 points was laid out, centered on the tower (Fig. 2), and this formed the sampling framework for most of the work. (A 50th point was measured at location J-2). The *T*-square method (see below) was applied on ten 650 m-long transects, radiating out from the tower at equal angles of 36 (Fig. 3). Sampling on these transects commenced at 250 m, and continued at 50 m intervals. This design was specifically to satisfy the sampling needs of the eddy covariance instruments on the tower.

Tree layer density, basal area and species composition

Trees were defined as woody plants taller than 2.5 m, regardless of the size or number of stems. All trees within 6 m of each of the 50 sample points were counted, classified to species, and had the circumference of all their stems immediately above the basal swelling measured to the nearest cm using a tape.

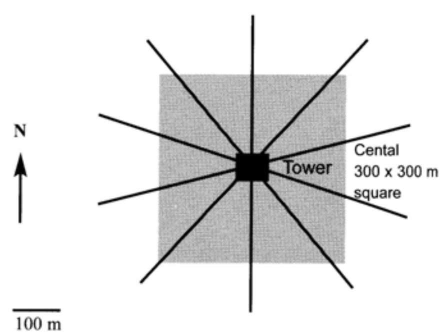

Fig. 3. The sampling sheme for tree basal area and density in various directions from the tower, and at a distance between 50 and 650 m away from it.

Their height was estimated to the nearest 0.1 m using a clinometer and Haglof sonic distance meter. Density per hectare was calculated by dividing the number of trees sampled by the sampled area (0.5542 ha). Basal area per stem was calculated from the stem circumference, assuming a circular section, and summed per circular plot.

Fifty tree basal area estimates were also made at the node points of the central grid using the Bitterlich technique (Mueller-Dombois & Ellenberg 1974). Every stem of Sclerocarya birrea within the central 300x300 m area was individually measured, to resolve a conflict between other estimators for this important species.

The *T*-square plotless method (Besag & Gleaves 1973) was applied at 50 points. At each point the distance to the nearest tree was measured using a tape as well as the distance between that tree and its nearest neighbour in the half-circle not including the original point. The density was calculated using the algorithm of Diggle (1983). Basal area was obtained by calculating the mean per individual basal area for each species (based on a pooled sample from this and other samples) and multiplying it by the density per species.

Tree and shrub canopy cover

Tree canopy cover (the area of tree crowns projected onto the horizontal plane, ignoring small gaps within the crowns, and allowing tree crowns to overlap) was measured at 50 points using a spherical densiometer (Lemon 1957). Shrub cover was measured by intersection with twenty 50 m long line transects, each 50 m apart and oriented N-S.

Effective plant area index is the projected area of leaves plus stems, as measured by radiation interception and assuming spherical canopies. It is the sum of the Leaf Area Index (LAI) and the Stem Area Index. It was measured between 09:00 and 09:30 on 23 June 2000 at a height of 0.6 m above the herbaceous layer at the 49 grid sample locations. A Decagon Accupar instrument was used with an unsegmented probe. This time was chosen so that the solar zenith angle was close to 60 from the vertical, thus minimising canopy leaf angle effects. The day was

Table 3

Tree density, height and basal area measured within the 300 x 300 m square centred on the flux tower. Values in parentheses are standard errors, sample size is 50

Species	Density		Height[a]	Basal area		
	Mean plants/ha	SE	Mean m	Circular plots m²/ha		Bitterlich
Combretum apiculatum	45	(10)	6.4	2.19	(0.54)	1.55
Sclerocarya birrea	14	(5)	12.3	1.48	(0.71)	1.73
Acacia nigrescens	7	(5)	10.3	0.21	(0.15)	0.69
Acacia nilotica	22	(7)	9.7	1.49	(0.51)	0.22
Ziziphus mucronata	16	(8)	11.1	0.79	(0.65)	0.31
Grewia bicolor	13	(6)	3.1	0.18	(0.09)	0.14
Lannea schweinfurthii	2	(2)	4.1	0.04	(0.04)	0.12
Acacia tortilis	2	(2)	3.2	0.03	(0.03)	0.02
Balanites maughamii						0.06
Peltophorum africanum						0.02
Spirostachys africana						0.08
Dichrostachys cinerea						0.12
Euclea natalensis						0.02
Diospyros mespiliformis	2	(2)	3.4			0.02
Grewia hexamita						0.02
Schotia brachypetala						0.04
Lonchocarpus capassa						0.06
Terminalia sericea						0.01
Carissa edulis	4	(4)	4.5	0.07	(0.07)	0.00
Totals	128	(16)	9.1	6.48[b]	(1.04)	5.23

Notes

[a] Weighted by stem basal area.

[b] Given that the true basal area for *Sclerocarya birrea* is 1.77 m²/ha, the plot total basal area is 6.77 m²/ha.

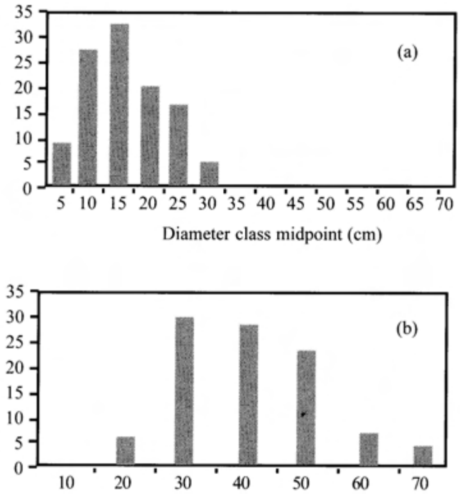

Fig. 4. The stem size distribution for (a) *Combretum apiculatum* and (b) *Sclerocarya birrea*

cloudless, and the fraction of direct sunlight was 0.8. The trees were nearly leafless on this date, thus this measurement provides an estimate of the stem area, a correction which allows leaf area to be derived from effective plant area measurements taken at times of greater leaf cover.

Herbaceous layer basal cover, biomass and species composition

Grass rooted basal area and soil cover state were measured using a Bruce-Levy frame 1.5 m long, with 10 needlepoints. The frame was placed in each cardinal direction, 2 m away from each of the 50 sample locations, making a total of 2000 points. The grass and forb standing crop was estimated at the 50 locations with a disk pasture meter (Bransby & Tainton 1977), 2 m NE of each grid location to avoid the effects of trampling. The pasture disk was calibrated at 15 locations by clipping, drying and weighing the herbaceous layer within 0.25 m^2quadrants. The contribution per species to the herbaceous layer mass was estimated using the Dry Weight Ranking technique (t'Mannetje & Heydock 1963).

Results

Unless otherwise noted, values following the symbol ± represent the standard error of the measurement, based on a sample size of 50. The tree basal area and density data for the central grid are given in Table 3. The stem size distributions for dominant species are illustrated in Fig. 4.

The tree crown cover was 28 ± 4 %. It did not differ significantly between the *Acacia* and *Combretum savannas*. The shrub cover was 7 %, and consisted mainly of several species of *Grewia*, including *G. bicolor*, *G. hexamita* and *G. monticola*.

The calibration equation for the disk pasture meter was as follows:

*standing crop (g/m^2) = settling height (cm) * 22.6 (± 8.4) ± 63 (± 110) (r^2 = 0.42; n = 12).*

The average herbaceous layer mass from 15 clipped plots was 300 gDM/m^2. The estimated standing crop from 50 pasture disc readings was 395 ± 33 g DM/m^2. The herbaceous standing crop was not significantly different between the upslope and downslope areas, but forage quality was slightly higher downslope. Summaries of the herbaceous layer composition, basal area and standing crop are given in Table 4.

Table 4

Grass rooted basal area and contribution per species to the herbaceous standing crop

Species	Basal area % mean	Basal area % (se)	Standing crop g/m^2
Panicum maximum	2.25	(0.33)	143
Digitaria eriantha	0.85	(0.21)	55
Pogonarthria squarrosa	1.55	(0.28)	50
Eragrostis rigidior	1.55	(0.28)	48
Sporobolus fimbriatus	0.60	(0.17)	43
Perotis patens	0.20	(0.10)	23
Urochloa mossambicensis			20
Aristida diffusa	0.15	(0.09)	11
Cyperus distans[a]	0.20	(0.10)	1
Melinus repens			1
Fimbristylis burchellii[a]	0.05	(0.05)	
Forbs	0.05	(0.05)	
All species	7.45	(0.57)	395 (30)

[a] Members of the sedge family (Cyperaceae)

At the ground surface 38 % of the soil was bare (although shielded by the grass canopy above it), 43 % was covered by leaf litter, 7 % by rooted plants, 4 % by fallen wood, 4 % by stones, 3 % by algal crusts, and 1 % by dung.

Discussion

The vegetation can be described as wooded grassland, which is a variety of savanna. In South Africa vegetation is structurally classified using a combination of information regarding tree cover and height and the herbaceous layer (Edwards 1983). As the trees are relatively tall (9 m), tree cover is greater than 10 % but less than 60 %, shrubs are much less prominent than trees, and there is a well-developed grass layer, this system classifies broadly as a savanna, i.e., a mixed tree-grass system. Savannas can be further subdivided into 'wooded grasslands' (also known as open savannas, or sometimes as parklands) and 'grassy woodlands', based on an arbitrary split below and above 30 % tree cover respectively. If only tree cover is considered, this savanna is just below the transition, and just above if cover by trees plus shrubs is included. (Tree and shrub cover in this savanna are approximately independent, so the total tree plus shrub cover is about 32 %).

The total basal area in the 300 x 300 m square around the tower does not differ statistically when measured by circular plot or by Bitterlich stick, but the two methods disagreed regarding the ranking of the dominant species. This is because of the effect of a few large trees such as *Sclerocarya birrea* (14 plants/ha, averaging 0.41 m in diameter) compared to that of *Combretum apiculatum* (45 plants/ha, 81 stems/ha, averaging 0.21 m in diameter). *Sclerocarya birrea* is easily under- or overestimated using the circular plot or *T*-square techniques, given the small sample fraction. A total count and measurement showed that the basal area of *S. birrea* in the central area was 1.77 m^2/ha and the density 13.8 plants/ha. The Bitterlich technique is plotless and efficient for sampling large, straight-stemmed trees such as *S. birrea*. Similarly, the best estimate for *Acacia nigrescens* is also from the Bitterlich method (0.7 m^2/ha).

Basal area is a good index of dominance, since it is directly related to both biomass and peak leaf area. The site as a whole can therefore be described as one third *C. apiculatum*, one quarter *S. birrea*, one fifth *Acacia nilotica*, one tenth *A. nigrescens*, with the remaining eighth contributed by 14 other species. The site encompasses two distinct plant communities, so it would be more accurate to describe it as two-thirds broad-leafed wooded grassland, co-dominated by *C. apiculatum* and *S. birrea*, and one third fine-leafed grassy woodland co-dominated by *A. nilotica*, *A. nigrescens* and *S. birrea*. The basal area did not differ statistically between the *Acacia* and *Combretum savannas*. Taking the above adjustments into consideration, the 'best estimate' of the basal area for the 300 x 300 m square is 6.77 ± 1.00 m^2.

The density estimates by the *T*-square method and by circular plot agree at around 130 trees/ha, but the basal areas estimated by the two methods did not. This is partly because the methods sampled spatially separate areas, but also because a few large individuals of *S. birrea* inflated the mean stem size used by the *T*-square method. When the pooled stem data (from Fig. 4 in this study as well as previous studies) were used to calculate a new mean, the basal area estimates are in statistical agreement. The vegetation in the quadrant south of the tower, but within the eddy covariance footprint, is mainly *Acacia* fine-leafed savanna, while that in the other directions is *Combretum* broad-leafed savanna.

Both the *T*-square method and the circular plot method permit the calculation of indices of aggregation. If the circles are small, the number of trees per circular plot has a Poisson distribution. If the trees are clumped, the mean variance ratio will be > 1 and if dispersed (regular), it will be < 1. According to this index, the trees within the

300 m x 300 m square are regularly spaced. The aggregation index from the *T*-square method is computationally more complicated (Diggle 1983). If it is below 0.25, it indicates dispersion and if above, aggregation. The data from the area between 250 m and 650 m away from the tower suggest aggregation. The departure from randomness is significant, but small, in both cases.

Plant Area Index in the *Combretum* savanna was measured as 0.07 m^2/m^2 in June 2000, and the Acacia savanna as 0.26 m^2/m^2 (giving a whole-site average of 0.15 m^2/m^2). On that date all *S. birrea* leaves had been lost, about half of the *C. apiculatum* leaves and a third of the *Acacia* leaves. The measured Plant Area Index can be taken as an upper estimate of the Stem Area Index for future calculations of LAI. Using allometric relationships and specific leaf areas for the dominant species (Scholes 1988; Shackleton 1998) and a generalised relation for the remainder (Rutherford 1980), the peak tree leaf mass is 88 gDM/m^2 and the peak woody plant LAI is probably about 0.67. The aboveground woody biomass is around 2800 gDM/m^2.

The grass standing crop of 400 g/m^2 is exceptionally high as a result of the record rainfall in the previous season. Assuming a grass specific leaf area of 9 m^2/kg, the peak grass LAI was over 3; in more average years it is probably around 1. The measured grass basal area of 7 % is also exceptionally high, 4 % would be more usual.

No detailed net primary production measurements have been made in this vegetation type, but they can be inferred from the work of Scholes (1988) and Shackleton (1998) to be about 270 gDM $m^{-2} y^{-1}$ aboveground in the *Combretum* savanna and 320 gDM $m^{-2} y^{-1}$ in the *Acacia* savanna. Belowground productivity in savannas (Scholes & Walker 1993; Scholes & Hall 1996) isbelieved to be slightly less than the aboveground production, giving an overall site NPP of around 410 gDM $m^{-2} y^{-1}$. The flux tower measures Net Ecosystem Exchange. This is expected to be very slightly negative (i.e., a small net flux of carbon from the atmosphere to the land, about -15 gC $m^{-2} y^{-1}$) in most years, to compensate for the efflux of around 80 gC $m^{-2} y^{-1}$ in fire years.

Conclusions

1. The flux tower is located on a sedge-covered seepline separating a *Combretum apiculatum-Sclerocarya birrea* wooded grassland on the sandy upslope side from an *Acacia nigrescens-Sclerocarya birrea* wooded grassland on the clayey downslope.
2. The two savannas have a similar basal area, of around 7 m^2/ha.
3. Grass production and palatability are slightly lower in the *Combretum apiculatum-Sclerocarya birrea* than in the *Acacia nigrescens-Sclerocarya birrea.*
4. The woody vegetation density and biomass is similar in all directions up to a distance of 650 m, but is dominated by *Acacia* species to the south and *Combretum* in all other directions.

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